HAROLD B. LEE LIBRARY
BRIGHAM YOUNG UNIVERSITY
PROVO, UTAH

CAPPING A BURNING OIL WELL

To extinguish a burning oil-well a kind of armoured trolley, fitted with a crane from which the cap is slung, is pushed near the blazing bore-hole. The extinguisher is then lowered.

QD
131.2
.P55x

THE WONDERS OF MODERN CHEMISTRY

BY

JAMES C. PHILIP, D.Sc., PH.D.

ASSISTANT PROFESSOR OF CHEMISTRY AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON

WITH TWELVE ILLUSTRATIONS & DIAGRAMS

B.Y.U.
LIBRARY
PROVO, UTAH

PHILADELPHIA
DAVID McKAY, PUBLISHER
604-8 SOUTH WASHINGTON SQUARE

B.Y.U.
LIBRARY
PROVO, UTAH

HAROLD B. LEE LIBRARY
BRIGHAM YOUNG UNIVERSITY
PROVO, UTAH

PREFACE

PROBABLY most people, when they think of Chemistry, suppose that its fascination and its practical bearings can be appreciated only by those who have access to some sequestered laboratory, the doors of which are closed to the uninitiated. This is a mistaken view, for in countless wonderful ways, unknown to the general reader, chemical science is supplying the ordinary needs and contributing to the conveniences of modern life.

In the present volume an attempt has been made to deal with this aspect of the subject, and the points of view adopted are different from those of the ordinary text-book. The author ventures to think that those readers who have no technical knowledge may be convinced that radium and other things which figure so largely in the newspapers are by no means the only scientific matters of thrilling interest; and perhaps even readers who are already familiar with the elements of the science may be helped to see afresh the many unsuspected and marvellous ways in which chemical forces are at work beneath our very eyes.

The chapters are so arranged that the reader who

takes them in order will understand what is brought before him much more easily than if he were to pick out subjects here and there. Only by such consecutive reading is it possible for him to secure the maximum of interest and instruction.

AUTHOR'S NOTE

THE author desires to express his indebtedness to the following firms and individuals for the kind help they have afforded him in connection with the illustrations of this book: Siebe, Gorman, & Co.; Price's Patent Candle Co., Ltd.; Thermit, Ltd.; Robertson Electric Lamps, Ltd.; British Aluminium Co.; Merryweather & Sons, Ltd.; United Alkali Co., Ltd.; the Director of the Deutsches Museum, Munich; Edward R. Bolton, Esq.; Charles Dawson, Esq.; Oscar Guttmann, Esq., A. D. Hall, Esq., F.R.S.; Sir Frederick Nathan; Dr. J. A. Voelcker.

He desires also to thank Dr. Frank Clowes & Messrs. Crosby, Lockwood, & Sons, Ltd., for permission to copy an illustration for Diagram 8.

CONTENTS

CHAPTER I

THE DAWN OF CHEMISTRY

PAGE

Chemistry in the ancient world—The metals and the planets—Rule of thumb—Speculation *versus* experiment—Fire, air, earth, and water 17

CHAPTER II

ALCHEMY AND THE PHILOSOPHER'S STONE

Chemistry in the Middle Ages—Sulphur and mercury—Transmutation of the metals—Apparent conversion of iron into copper—Opportunity for quack chemists—Evils of alchemy, and how it became a matter of history only . . . 21

CHAPTER III

NATURE'S BUILDING MATERIAL

Animal, vegetable, and mineral—Organic and inorganic—The irreducible minimum — Elements, and how they become partners—The difference which chemical forces make—Atoms and molecules—Something beyond the power of the microscope 28

CHAPTER IV

INVISIBLE SUBSTANCES, AND HOW WE KNOW OF THEIR EXISTENCE

Believing without seeing—How we discover gases—Hydrogen and balloons—The air we breathe—Candles and mice as danger-signals—How a gas accommodates itself to circumstances—Restless activity where there is apparent stagnation —Gas molecule *versus* express train 39

CHAPTER V

ELEMENTS WITH A DOUBLE IDENTITY

How an element changes its nature without changing its name—Red and yellow phosphorus — Diamond and charcoal — Artificial diamonds—The diamond useful as well as ornamental — Oxygen and the "smell of electricity"—Two molecules which are the same externally may differ in their anatomy—A curious case of self-effacement in crystals . . 50

CONTENTS

CHAPTER VI

METALS, COMMON AND UNCOMMON

PAGE

An aristocracy among the metals—Gold and platinum—Iron in modern life—Cast-iron, wrought-iron, and steel—How razors and watch-springs are hardened—Aluminium and its affection for oxygen—Thermit—A metal that does not tarnish—Platinum in electric lamps—Why we want tantalum nowadays 61

CHAPTER VII

WHERE TWO METALS ARE BETTER THAN ONE

Metals not always what they seem—Tinplate, galvanised iron, and the common pin—Why a sovereign is not made of pure gold—Common solder—Fire-alarms and sprinklers—The melting-point of alloys 72

CHAPTER VIII

ACIDS AND ALKALIS

What an acid is, and how it may be "killed"—Engraving on metals—An ink which marks glass—Oil of vitriol and its love for water—The chemical fire-engine—Alkalis as antidotes—How one may safely enter a poisonous atmosphere—Ammonia and lime—Energy manifested in the slaking of lime—Mortar the scene of unceasing chemical activity 82

CHAPTER IX

NATURAL WATERS, AND WHAT THEY MAY CONTAIN

How two gases make one liquid—Some physical peculiarities of water—Hard and soft water—The making of a lather—Carbonate of lime and the "furring" of a kettle—Stalactites, stalagmites, and petrifying springs—How fresh water is obtained from sea water—Germs in water and their removal—Seltzer water, Epsom salts, and sulphur springs . 95

CHAPTER X

CHEMICAL CHANGES WHICH PRODUCE LIGHT AND HEAT

The "Red Flower"—Chemistry of a Candle—The use of a lamp chimney—Can smoke be abolished?—Gas stove *versus* coal fire—The Bunsen burner—The wonderful changes that accompany combustion—Slow burning in the human body—How two men are equivalent to one gas burner—Rusting a kind of slow combustion 106

CONTENTS

CHAPTER XI

HOW FIRE IS MADE

PAGE

Fire by friction—Two minutes required to get a light—Flint and steel—Fire syringe and burning-glass—The first lucifer matches—The dangers of phosphorus, and how they are avoided—Three hundred million matches a day in England—Döbereiner's lamp and catalytic action—A modern cigar-lighter—Spontaneous combustion—Why haystacks and oily rags take fire of their own accord 118

CHAPTER XII

NATURE'S STORES OF FUEL

Wood, peat and coal—Why burning wood blazes more than burning coal—How an American engineer "struck oil"—Subterranean reservoirs in the United States and Russia—Natural gas in England—When will it be necessary to carry coals to Newcastle?—Fuel from peat bogs—Potatoes a source of fuel 131

CHAPTER XIII

MORE ABOUT FUEL

A juvenile experiment in the making of coal gas—What happens when coal is heated—Valuable products from the gasworks—Coke for iron-smelting—Water gas—The energy latent in a pound of coal—Liquid *versus* solid fuel—George Stephenson and "bottled-up sunshine" 142

CHAPTER XIV

FLAME: WHAT IS IT?

Flame not always a feature of combustion—How air may be burned—The structure of a flame—What makes a flame luminous—Candles at the top of Mont Blanc—Ignition temperatures—Risk of flames in "gassy" mines—Davy's safety lamp—How fire-damp is detected by flame-caps . . 154

*

List of Illustrations

CAPPING A BURNING OIL WELL . . *Frontispiece*

AN ALCHEMIST'S LABORATORY . . . *Page* 24

MOLTEN IRON WITHOUT A FURNACE . . 64

A CHEMICAL FIRE-ENGINE 88

A WONDERFUL RESULT OF PROLONGED CHEMICAL ACTION. 96

A WONDERFUL CEILING 104

A BIG BLAZE AT BAKU 110

NATURAL GAS IN ENGLAND 140

The contents of this book have been taken from Professor James C. Philip's larger book entitled "The Romance of Modern Chemistry," published at five shillings.

THE ROMANCE OF MODERN CHEMISTRY

CHAPTER I

THE DAWN OF CHEMISTRY

IN this twentieth century chemistry has become a veritable storehouse of wonder, a cavern of marvel and mystery. Many generations of scientific workers have done their share in the exploration of the cavern and in the discovery of keys to its innumerable chambers—but much that is obscure or unknown remains. To-day there are more explorers than at any previous time, more eager spirits than ever seeking to gain an entrance into those chambers which have not yet yielded up their secrets. Ever and anon some worker, more ingenious or more fortunate than his fellows, makes a notable advance, and his name is on every one's lips. But all the time, unthought of by the outside world, the rank and file of the explorers is steadily pushing forward and conquering nature's mysteries for the ultimate service of man.

In this volume we shall take a peep into some of the chambers which the workers of the past have opened up to us, as well as into some of those which are still partly unexplored. We shall see how the subtle chemical forces which are at work all around us have been revealed and harnessed for the use of man, and how order has been introduced into the apparently hopeless confusion of chemical phenomena.

THE DAWN OF CHEMISTRY

It is not easy to say definitely where and when man first began to grope after the knowledge of chemistry. Of all the ancient nations the Egyptians seem to have been the most prominent in this respect; their knowledge, however, was not acquired in any systematic way, but was rather the result of chance observation. By comparison with the store which has been accumulated in the intervening centuries, the chemical knowledge of the ancients was a negligible quantity. They stood merely on the threshold of the storehouse, little dreaming of the spacious chambers into which succeeding generations were to find their way.

Suppose we consider for a moment what actually was the sort of chemical knowledge possessed by the nations of antiquity. They were acquainted with seven metals, namely, gold, silver, copper, tin, iron, lead, and quicksilver, and although some of these—gold, silver, and copper to a smaller extent—are found as such in nature, the others would have to be extracted from their ores; the ancients must therefore have been familiar with the metallurgical processes necessary for this purpose. It was not long before these seven metals became associated with the sun, moon, and the then known planets, each metal receiving the name and symbol of one heavenly body as shown below:—

Gold	. .	The Sun	. . ☉
Silver	. .	The Moon	. . ☽
Quicksilver	.	Mercury	. . ☿
Copper	. .	Venus	. . . ♀
Tin	. . .	Jupiter	. . . ♃
Iron	. .	Mars	. . . ♂
Lead	. .	Saturn	. . . ♄

This method of representing the metals by symbols sur-

vived till the Middle Ages, and in old prints one may see a flask or bottle within which is sketched a representation of the sun. This is to be taken as indicating that the flask or bottle contains a solution of gold.

Besides metallurgical operations the processes of soap and glass manufacture, of pottery making, and of dyeing were known and practised in ancient times. Such substances as lime, acetic acid, sugar, soda, potash, alum, and oil of turpentine were in frequent use. The manufacturing processes just mentioned are all essentially chemical, but they were carried out merely by rule of thumb, and not on any scientific plan. This is not to be wondered at, for the practical operations were in the hands of artisans alone, and it was not the correct thing for the philosophers of the ancient world to bring their wisdom to bear on arts and crafts. There was in fact a complete divorce between the practical and the theoretical, and therefore no real science; the educated people did not come into touch with the experimental facts on which alone a science could be soundly based.

The proper sphere of philosophers was considered to be speculation pure and simple, and to such purpose did they speculate on casual observations that the most grotesque theories were evolved, quite out of harmony with actual facts. An instance of the sort of thing to which this purely speculative science led is furnished by an argument of the eminent philosopher Aristotle. As a result of some of his speculations he came to the conclusion that a vessel filled with ashes would contain as much water as one of the same size which has no ashes in it. But there was absolutely no desire to see whether this was actually the case or not. These philosophers in fact stood on the threshold of Nature's storehouse,

endeavouring to predict what should be found within, but never making any attempt to effect an entrance, and see how the facts squared with their predictions.

In one respect, however, the chemical speculations of the ancient philosophers demand some attention, and that is in regard to the ultimate constituents of the visible world. There were supposed to be four primitive independent substances or elements, namely, fire, air, earth, and water, by the combination of which in different proportions the most varied products could be obtained. According to Empedocles, for example, flesh and blood consist of equal parts of all four elements, while bones are one-half fire, one-quarter earth, and one-quarter water.

The word "element" applied to these primitive independent substances has scarcely the same meaning as that which we nowadays attach to it, and indeed Aristotle regarded fire, air, earth, and water as the manifestation of different properties carried about by one and the same kind of matter. The four adjectives "warm," "cold," "dry," and "moist," describe the fundamental qualities which he supposed to be associated with this primordial matter, and to each of the four elements were assigned two of these properties. Air was represented as warm and moist, water was moist and cold, earth was cold and dry, fire was dry and warm.

All this seems very fantastic, but it was a way of looking at things that was current for a long time after Aristotle, indeed down to comparatively recent times. We may well wonder whether the views which we hold about the origin and composition of the natural world will be thought equally fantastic by our scientific descendants!

CHAPTER II

ALCHEMY AND THE PHILOSOPHER'S STONE

IN the previous chapter it was suggested that the historical development of chemistry has resembled the gradual exploration of a cavern full of wonder and of treasure. The reader must not suppose, however, that the progress of the exploration has at all times been equally rapid and equally important. On the contrary, there have been centuries during which chemists contributed very little to the real advance of their science, simply because their explorations were carried out under an entirely false guiding principle.

This remark applies to the long period in the Middle Ages during which devotion to alchemy was supreme, and although the alchemists in the course of what some one has called their "potterings" found out many new substances, and invented many useful processes, their work was singularly unproductive in the interpretation of chemical phenomena, and in the discovery of general principles. They missed the spacious chambers in the cavern because in their blind adherence to the idea that it was possible to convert the baser metals into gold, they lost their way in subterranean passages where little treasure was to be found.

We have seen that in the nations of antiquity the theoretical and practical sides of natural science were kept absolutely separate. This state of affairs, so dis-

astrous to the advance of true science, was remedied to some extent in the Middle Ages, for the alchemists were not only practical experimenters, but also, many of them at any rate, men of considerable learning and intellectual ability. Unfortunately, however, their chemical theories were based on the fantastic views of the ancient philosophers, and to these theories the alchemists stuck like limpets to the rock. They had yet to learn that the true method of advance in science is first to study the phenomena and collect the facts, and then build up a theory; the alchemists, on the other hand, preferred to start with an *a priori* theory, and then to try to make the facts fit into it.

Curiously enough, the theory of the transmutation of the metals, which dominated the chemistry, or rather alchemy, of the Middle Ages, came in the first place from Arabia. After their conquest of Egypt in the seventh century A.D. the Arabians probably absorbed and developed such scientific knowledge as was then in existence, and in any case the first man, a satisfactory record of whose chemical work has come down to us, was an Arabian, Geber by name. He had quite a remarkable amount of practical chemical knowledge for that early time; many kinds of apparatus, and many laboratory operations, such as distillation, filtration, and crystallisation, which are indispensable to every chemist, were familiar to him.

Valuable as Geber's practical work was, his theories about the nature of the metals were very wide of the mark. He considered that the metals were all composed of sulphur and mercury; these two substances, or two principles which were embodied in them, were regarded as the "parents" of all the metals. One metal was

supposed to differ from another only in the proportion of mercury and sulphur which it contained; thus gold was particularly rich in mercury, whereas the common metals had a large proportion of sulphur. On this view it ought to be possible to change one metal into another by merely altering the relative proportion of the two constituents, and the problem of transmuting lead or copper into gold would then be reduced to the discovery of some agent which would withdraw sulphur from the baser metal and add mercury to it.

That this way of looking at things should be accepted at all is perhaps not so very strange when we consider what the thinkers of a thousand years ago had inherited from Aristotle and other ancient philosophers. We have seen that Aristotle regarded fire, air, earth, and water as different properties carried by one original kind of matter, and it is not a very big step from this view to the belief that by simply modifying its properties one kind of matter could be converted into another kind. Since water was regarded as moist and cold, while air was moist and warm, it was thought possible by heat alone to convert the second chief property of water into the second chief property of air; that is, it was believed that water could be transformed into air.

So we see that the views of Geber and the alchemists who followed him in the Middle Ages were more or less a natural development of the speculations of the ancient philosophers. What is difficult to understand is how the belief in the transmutation of metals continued to dominate the study of chemistry so long as it did, for it was not until the beginning of the eighteenth century that chemists became generally sceptical about the possibility of converting base metal into gold. For the

space of eight centuries or thereabout the efforts of the great majority of those people who studied chemistry were directed to the discovery of the Philosopher's Stone—the Great Elixir which should have the power of changing lead or any other common metal into the noble gold.

If we are to trust the records that have come down to us, the philosopher's stone was not only sought for, but found,—by a few favoured individuals. An eminent physician and chemist, van Helmont by name, who lived in the seventeenth century, states that with a small specimen of the philosopher's stone, received from an unknown source, he had transformed a considerable quantity of mercury into pure gold. A little later a physician in the household of the Prince of Orange published a detailed description of the way in which, with the help of a certain preparation, he had effected the transmutation of lead into gold.

What are we to make of these stories? For no single chemist nowadays believes that anybody ever succeeded in producing so much as one grain of gold from any of the baser metals. The two men whose statements about the production of gold have just been quoted were eminently respectable, and there seems to be no ground whatever for supposing that they wished to deceive their contemporaries or posterity. The only conclusion to which we can come is that they were themselves deceived, that they were the victims of illusion. That seems to be the most charitable explanation.

We may, however, ask the question whether there was anything at all to account for the transmutation of metals being regarded as an incontrovertible fact for so long a period. No doubt the ancient tendency to place more

By permission of the *Deutches Museum, Munich*

AN ALCHEMIST'S LABORATORY

This is a photograph of the reconstructed alchemist's laboratory in the new German museum at Munich. The most prominent features are the furnaces and the fantastically shaped retorts for carrying on distillation.

trust in an abstract theory than in any experimental facts had something to do with the persistence of the belief, but in addition certain chemical phenomena were known, which to a superficial observer would seem to show that one metal could be converted into another. For example, there is the experiment, which any one may repeat, of putting a piece of iron, such as a steel knife-blade, into a solution of blue vitriol or sulphate of copper. However short a time the iron is left in the blue vitriol solution, it comes out exactly like copper, with the same characteristic reddish colour. This is a very simple straightforward experiment, and to the alchemist it admitted of no other explanation than that the iron had been converted into copper. We know now that no such change takes place: some copper comes out of the solution and is deposited on the surface of the iron, while by way of holding the balance even, an equivalent amount of the iron passes into solution.

Other circumstances also favoured the postponement of the day when the truth about the transmutation of metals was to be recognised. For one thing, the alchemists received valuable support from princes and rulers who were in financial difficulties. It was thought distinctly worth while to have a man about court who might be able to produce gold out of practically nothing, and alchemists were therefore encouraged to continue their search for the philosopher's stone, often at considerable expense to their patrons. This money aspect of the business, as the reader will easily understand, led naturally to all sorts of quacks and charlatans setting up as alchemists, and imposing on the credulity or stupidity of princes who were in want of money.

Again, the air of secrecy which pervaded the alche-

mists' doings and writings helped to smother the truth. Naturally, a man who thought he had discovered the philosopher's stone and could turn lead into gold, was very careful not to let his secret get abroad, for if every one knew the trick, the gold would have no more value than the lead out of which it was made. Hence the writings of the alchemists are full of the most unintelligible nonsense that was ever put on paper. Many of them profess to describe their method of preparing the philosopher's stone, but the description consists of nothing but foolish jargon.

Perhaps the best way to bring home to the reader the extraordinary character of the alchemistic writings is to quote the following translation from a book on alchemy that appeared in 1608. The philosopher's stone is supposed to be describing itself: "I am the old dragon that is present everywhere on the face of the earth ; I am father and mother ; youthful and ancient ; weak and yet more strong ; life and death ; visible and invisible ; hard and soft ; descending to the earth and ascending to the heavens ; most high and most low ; light and heavy ; in me, the order of nature is oftentimes inverted, in colour, number, weights and measure. . . . I am the carbuncle of the sun, a most noble clarified earth, by which thou mayest turn copper, iron, tin and lead into most pure gold."

The philosopher's stone was supposed to possess the most marvellous power, Roger Bacon, one of our own countrymen, declaring that it was able to transform a million times its weight of base metal into gold. Besides this it was supposed to have the power of prolonging life, and was therefore regarded as an "elixir vitæ." Many other beliefs held at that time were, however,

equally absurd. Thus, for example, it was thought that just as an exhausted soil becomes fertile again after a time of rest, so a gold mine which was exhausted would, if left to itself for a long period, again yield abundance of the precious metal!

As time went on many chemists, while still adhering to their belief in the transmutation of metals, began to work on other and more useful lines. One school, headed by Paracelsus, devoted themselves to studying the bearing of chemistry on medicine, and made a number of valuable discoveries in this direction. Paracelsus taught that "the object of chemistry is not to make gold, but to prepare medicines," and although this by itself is rather a limited field, it had the effect of gradually drawing men away from the pursuit of alchemy. The way was thus prepared for the rejection of the alchemistic doctrines, which had so long rested like a blight on real chemical science. A healthy desire arose to investigate chemical phenomena for the sake of knowledge alone, and it was under these conditions that Nature began to reveal her secrets more rapidly. Especially when the explorers discovered the great value of the balance and learned what it had to teach them about the commonplace phenomena of burning, they got back again to the right lines of exploration. From that day to this there has been on the whole steady progress, and it is now our task to look at some of the secret marvels of Nature which have been revealed in these last one hundred and fifty years.

CHAPTER III

NATURE'S BUILDING MATERIAL

A COMMON way of classifying natural objects is suggested by the familiar questions—"Is it animal?" "Is it vegetable?" "Is it mineral?" Now, although from the chemical point of view we are chiefly concerned with so-called "dead" matter, there are many things belonging to the animal and vegetable kingdoms which we must take into consideration. A certain object may be assigned to one of these two kingdoms, not because it is at present alive, but simply because at one time or another in its history it has been a part of a living thing, a plant or an animal. A bone, for example, would be considered to belong to the animal kingdom, although in itself it is as dead as a door-nail, apart from the living and throbbing body of which it was a member. A tree that refuses to become green under the touch of spring would still be regarded as "vegetable," although, so far as growth is concerned, it might as well be a block of granite.

What makes all the difference between the mineral kingdom on the one hand, and the animal and vegetable kingdoms on the other hand, is the mysterious thing called "life," not the mere materials of which the various objects are built up. It is no doubt true that the materials associated with plants and animals, and thus involved in the processes of life, are frequently of

104391

a special kind, and this is indicated by describing them as of "organic" origin, in contrast to the "inorganic" substances which are more especially characteristic of the mineral kingdom. It used to be thought up to about one hundred years ago that organic substances could be produced only under the influence of life, but this has been found to be a mistaken view. The chemist can produce organic substances in the laboratory, starting with inorganic materials, and the organic substances so produced are the same in all respects as those formed in the living organism. But however much the chemist may pride himself on his achievements in building up organic substances, there is one thing he has not been able to do, and that is to produce an organism, even of the most elementary kind. Life, which makes all the difference between the organic substances and the organism, is apparently beyond the resources of human manufacture. Its origin must be traced to a higher source.

A little thought will suffice to remind us of the diverse material used in building up our world, both organic and inorganic. Besides the coal and the minerals which we extract from below the crust, and the many things which we grow on the surface of this little island, we have at our disposal nowadays the products of the ends of the earth in all their variety. But a little simplification may be introduced into this extraordinary diversity when we bear in mind that the chemist has been able to split up most of the complex substances with which we are familiar. He has shown that by various agencies, such as, for example, the action of heat, a complex substance may be broken up into simpler substances, these latter into still simpler ones, and so

on. At last we arrive in this way at an irreducible minimum of substances which obstinately refuse to break up into anything simpler, and which cannot be converted into each other.

These elements, as the chemist calls them, are, so to speak, the bricks out of which all known substances are built up. They number about seventy, and each kind of brick possesses characteristics which distinguish it from all the other kinds. That being so, it is not difficult to understand how the combination of the elements leads to all the infinite variety of nature. For the reader will see at once that if he was provided with seventy kinds of bricks, each kind with its own characteristic shade of colour, and if he was required to put together a structure containing at least two kinds of bricks, and up to any number of bricks of each kind, there would be a countless host of products.

Now what are these seventy fundamental substances? Many of them are familiar to the reader, by name at least; for example, lead, sulphur, gold, copper, phosphorus, oxygen, mercury, tin, hydrogen, silver, and carbon. But quite half, probably, of the elements are unknown, even by name, to the ordinary individual, whilst to the chemist himself they are frequently not much more than names. And this is not to be wondered at; for the importance of some of the elements, judged by the part they play in the building up of the world and in the service of man, is extremely small. Thus glucinum, gallium, scandium, and many others would not be much missed were they to disappear altogether from the family of the elements.

Any one who wants to understand something of the fascinating science of chemistry must be quite clear

about the part played by the elements and about the relations in which they stand to the infinite variety of naturally occurring substances. Amongst the elements themselves there is great diversity. Some are gaseous substances, like oxygen, hydrogen, nitrogen, chlorine, and helium ; two are liquids under ordinary conditions, namely, mercury and bromine ; while the great majority, chiefly metals, are solid substances. But this division of the elements into gaseous, liquid, and solid substances is somewhat arbitrary, and is valid only for the particular conditions which prevail on our earth. On those heavenly bodies which are much hotter than our planet, many of the elements with which we are familiar as solids exist in the gaseous condition. In the extraordinary heat which prevails on the sun even iron is a vapour.

It must be borne in mind that the elements are found in nature mostly in some form of mutual combination. Only a few of them occur in the uncombined state, or "native" as it is called. The noble metals and some other elements, such as copper, sulphur, oxygen, and nitrogen, belong to the latter class, but the minerals composing the great bulk of the earth's crust are combinations of the other elements with oxygen and sulphur. The fact that some elements never occur in the native condition becomes intelligible when we make ourselves acquainted with the properties of these elements. Take the case of phosphorus. The chemist has been able, by certain subtle processes, to extract this element from the ashes of bones, but it has such an aversion to the state of single blessedness, that unless precautions are taken to keep it out of contact with air, it reverts to the combined state and unites with the oxygen of the atmosphere. It is therefore easily understood why phosphorus is never

found native, and a similar explanation is forthcoming in the case of other elements.

It may occur to the reader to ask—Is it quite certain that the so-called elements represent the ultimate units of which the natural world is built up? Is it not possible that some substances which are at present regarded as elements may turn out to be combinations of other elements? This is perfectly possible, but not very probable. It is certainly true that water, soda, and potash, which up to one hundred or one hundred and twenty years ago were regarded as elements, were then found to be really compound substances, and it is conceivable that a similar thing might happen again. But it is less likely nowadays, for a substance which has to run the gauntlet of the chemist's modern methods of attack can scarcely pass unscathed unless it is really of an elementary character.

On the question how far the present accepted list of elements is to be regarded as final, the discovery of radium has thrown an interesting and somewhat startling light. For it appears that radium, although an element in the commonly accepted meaning of the word, is undergoing continuous transformation into other elements, the gas, helium, being one of the products of change. The idea that one element could be transformed into another was cherished by the alchemists, as we have seen, but the whole course of chemical progress in the last century was against the acceptance of that idea. And just as chemists were getting settled in their minds about that important question, radium came along and introduced an air of uncertainty again into the whole business. If it should turn out that one element can actually be converted into another, as radium appears to be changed into helium, there will be some support given to the hypothesis that the

elements are simply modifications of one original parent substance. This plausible suggestion was made long ago, and has been revived at occasional intervals, but the evidence of experiment has so far been against its acceptance.

In the earlier part of this chapter the elements have been frequently referred to as existing in a state of combination, in the form of compound substances. Now a compound of two elements is something quite different from a mere mixture. The two elements which combine do so in a very thorough and intimate fashion, with the result that each, as it were, loses its own individuality, and an entirely new individual, with other characteristics, is produced. The two differently coloured bricks, which we may suppose to represent the two elements, are not merely laid side by side so that we could lift the one away from the other without any trouble, but they are fused and coalesced in some mysterious manner into one new brick, different in shape and colour from each of the two original ones. The only statement we can make with certainty about the new brick is that its weight is equal to the sum of the weights of the two component bricks.

It is very interesting to observe that in some cases we can start with two elements and make either a mixture or a compound of them. Two such elements are iron and sulphur. If the iron is taken in the form of fine filings, which are grey in colour, and if these are intimately mixed by grinding with sulphur, which is yellow, a powder is obtained which is intermediate in colour between grey and yellow. And in this mechanical mixture each component retains its own characteristics just as if the other were not there. The particles of iron can be drawn out of the mixture with a magnet; the

particles of sulphur can be dissolved out by using a suitable liquid. The reader will therefore see that it is a comparatively easy matter to separate the components of a mechanical mixture.

Suppose now that some of the iron-sulphur mixture is put in a tube and that the tube is heated by a flame at one end. Something of importance obviously takes place, for the contents of the tube above the flame begin to glow vigorously and are raised to a white heat. Even if the tube is no longer heated externally, the flame being removed, the glowing continues until the zone of incandescence has passed right through from one end of the iron-sulphur mixture to the other. This extraordinary display of energy is evidence that the iron and sulphur are combining chemically, and if the product is examined when it has cooled, it will be found that a new substance with entirely different properties has indeed been produced. There are no iron particles now to be attracted by the magnet, and no liquid can be found which will extract the sulphur and leave the iron behind. The iron and sulphur particles are no longer lying side by side; they have united and coalesced to form a compound —sulphide of iron—the properties of which are quite different from those of iron and sulphur. Countless other illustrations might be cited of the fundamental difference between a mere mixture of two elements and a chemical compound of the two. A familiar case is gunpowder. This is a mechanical mixture of sulphur, carbon, and nitre, and it is only when the gunpowder is fired that the real chemical process begins. This process results in the production of a number of new substances—gases—absolutely different from the original constituents of the gunpowder.

Apart from the thorough-going change of properties which accompanies the combination of two elements, chemists have discovered some very remarkable facts bearing on the proportions by weight in which combination takes place. Elements are exceedingly particular as to how far they give themselves away, and nothing will persuade them to go more than a certain distance in meeting the advances of other elements. When iron and sulphur combine, they do so in the proportion of seven parts of iron to four parts of sulphur. If a mixture of eight ounces of iron with four ounces of sulphur were heated, nothing would induce that extra ounce of iron to give up its independence and enter the compound. And similarly if we took a mixture of seven ounces of iron with five ounces of sulphur, the extra ounce of sulphur would absolutely refuse to be anything else than sulphur. So that elements combine in perfectly definite proportions. However or wherever a compound is produced, in the laboratory of the chemist or in the laboratory of Nature, it invariably consists of the same elements united in exactly the same proportions.

There are cases, indeed, in which two elements unite to form more than one compound. Thus there are two oxides of copper, one containing eight parts by weight of copper to two parts by weight of oxygen, and another containing eight parts of copper to one of oxygen. Observe that the amount of oxygen uniting with eight parts of copper must be either one or two ; no compound can be formed containing between one and two parts of oxygen to eight parts of copper. And this is merely an example of what is always found to be the case. When one element combines with another element to form more than one compound, the amounts of the second element

which combine with a definite weight of the first element are as one to two, or two to three—some simple ratio of that sort.

These remarkable facts about the proportions in which the elements combine were discovered soon after the balance had become part of the regular equipment of a laboratory, and chemists began to cast about for an explanation. The result was that they came to regard matter as made up of separate particles of extremely small size called molecules, which were incapable of further division except by chemical means. A fragment of iron, if magnified sufficiently, would thus resemble a heap of cannon balls, each cannon ball representing a molecule. It must be remembered, of course, that this is only a theory, a picture, for nobody has ever divided matter so finely that further division was impossible; a single separate molecule has never been picked out; indeed, it must be much smaller than anything that has ever been seen, even under the most powerful microscope.

Although the molecule of a substance is the smallest particle of that substance which can exist by itself, it is possible to break it up by chemical means. The chemist's experiments have led him to believe that a molecule consists of so-called atoms, sometimes all of one kind, sometimes of different kinds. When the atoms in a molecule are all of the same kind, it is an element which we are considering; when the atoms are of different kinds, it is a compound. To separate the atoms which are present together in any one molecule, we bring another kind of molecule, with different atoms, alongside. In a great many cases the atoms will promptly change partners, and new molecules—that is, new substances—are produced. Suppose, for example, we bring together a molecule AB,

containing one atom A and one atom B, and another molecule CD, containing one atom C and one atom D, then a chemical reaction will take place resulting in the formation of two new molecules AC and BD, or possibly AD and BC.

This way of picturing the constitution of matter enables us to explain the definite proportions in which elements are found to combine. Take the case of copper and oxygen, already mentioned. Chemists have come to the conclusion that the atom of copper is four times as heavy as the atom of oxygen. Now the simplest way in which combination could take place would be by one atom of copper joining with one atom of oxygen, to form one particle or molecule, as it is called, of copper oxide. Each molecule, therefore, of copper oxide would contain four parts by weight of copper to one part of oxygen, or, what is the same thing, eight parts by weight of copper to two parts of oxygen. And what has been said of each separate molecule may be said also of the mass of copper oxide, which is simply the sum total of the myriad separate molecules. The proportion of copper to oxygen in the mass of copper oxide would be the same as in each individual molecule.

Remembering that the atoms are indivisible, we can easily see that the next simplest ways in which copper could combine with oxygen would be by two atoms of copper joining with one atom of oxygen, or by one atom of copper joining with two atoms of oxygen. The atom of copper being four times as heavy as the atom of oxygen, the first of these two compounds would contain eight parts by weight of copper to one part of oxygen, while the second would contain eight parts by weight of copper to four parts of oxygen. As mentioned above, one of these

compounds, the first, has actually been discovered, and it is probable that the second also exists.

With the atomic theory of the constitution of matter, therefore, we can explain the very notable simplicity and constancy which characterise the manner of combination of the elements.

CHAPTER IV

INVISIBLE SUBSTANCES, AND HOW WE KNOW OF THEIR EXISTENCE

"SEEING is believing" is a familiar proverb, but we must recognise that the saying does not contain all the truth about the relation of seeing to believing, and that we believe in many things which we cannot see. Even in the realm of matter, apart altogether from the realm of mind, there are some things the existence of which is not directly obvious by the evidence of our senses. The chemist, whose business it is to deal with all sorts and conditions of matter, knows many substances—"gases," he calls them—of which he could not say—"There! See, smell, touch, taste." A gas may be without smell or taste, it may be as intangible as a spirit, and as for seeing it, why, it may be off and away while the observer still thinks he is looking at it. And yet it is possible to satisfy ourselves by some more or less indirect observations that these invisible, odourless, intangible, and tasteless substances do really exist. The chemist, at least, believes in the existence of gases such as oxygen, hydrogen, nitrogen, and carbon dioxide as firmly as he believes in the existence of iron, sulphur, turpentine, or water.

It must be observed that the difficulty which is met with in the case of the four gases just mentioned does not occur with all gaseous substances. Some betray their

presence by their smell; coal gas, for example, is invisible, but fortunately our noses soon warn us when it is out of bounds. Other gases, again, are coloured, and we have thus direct evidence of their presence.

But there are several indirect ways in which we may convince ourselves that air, oxygen, nitrogen, hydrogen, carbon dioxide, and similar elusive substances have a material existence. Air is indeed invisible, but from the effects which it produces when in motion we may be pretty sure as to its material nature. In every case where mechanical work is done, we shall find on consideration that the origin of it lies in the motion of some material body; and the wind, which in its destructive mood can lay low a whole forest, can be regularly harnessed to work by the sails of our ships and the arms of our windmills. Since work is done by the wind, there must be a material body moving, and the material body, in this case, is the air.

A very good reason for regarding air as a material substance is based on the fact, to which every reader will assent, that two different material bodies cannot occupy a given space at the same time. If we are foolish enough to run against a stone wall we learn by experience that one material body resents the attempt of another material body to take its place; it offers resistance. Now that is exactly how the air and other gases behave. If a tumbler is inverted in a basin of water, the water does not rise and completely fill the tumbler. There is something inside which takes up room and so offers resistance to the water occupying the same space. Reasoning from our general experience of material bodies, we may conclude that the invisible something inside the tumbler is certainly of a material nature.

Once again—all solid and liquid substances with which we are familiar are characterised as light or heavy—in other words, they have weight. In this respect also air and other gases conform to what is commonly characteristic of all material bodies. It is true that, bulk for bulk, gases weigh much less than water, or wood, or stone, but the difference is only one of degree. One simple way of showing that air has weight is to put a little water in a glass flask, and let it boil vigorously until the flask is full of steam. It is then corked tightly and removed at once from the source of heat. When the flask and its contents have become quite cold, they are put on one side of a sensitive balance, sufficient weights being put on the other side to keep it level. The cork is then removed for a moment, and it will be observed that the side of the balance on which the flask was placed goes down at once, showing that the mere opening of the flask causes it to become heavier. What has happened is that the steam which filled the flask when it was hot became condensed to water when the flask had cooled, thereby leaving room for air to enter as soon as the cork was removed. It is the entrance of this invisible something from the surrounding atmosphere which makes the flask heavier. Gases, then, have weight, and are on this ground also to be reckoned as material substances.

As has been said already, gases are very light compared with other substances; they are matter in a very attenuated form. A pint of water is nearly 800 times as heavy as a pint of air, and with the gas hydrogen the contrast is still more marked. For air is fourteen and a half times as heavy as hydrogen, so that a pint of water weighs 11,500 times as much as a pint of hydrogen. It may truly be said that a pint of hydrogen is as light as

the proverbial feather, for its weight is only between one five-hundredth and one six-hundredth of an ounce. Hydrogen is, in fact, the lightest substance known.

The fact that hydrogen is so much lighter than air is of great importance in the manipulation of balloons. In order that a balloon may itself rise in the air and carry as well a load in its car, it must be filled with something which is considerably lighter than air. For this purpose hydrogen is the ideal substance, but coal gas, which contains a good deal of hydrogen, is often employed. Bulk for bulk, coal gas is about half as heavy as air.

We have been comparing air with hydrogen, but it is important to bear in mind that whereas hydrogen is an element, air is a mixture chiefly of the two elements, oxygen and nitrogen, in the proportion of one volume of the former to four volumes of the latter. Air is not a chemical compound of oxygen and nitrogen, and from what has been said already about the essential difference between a mechanical mixture and a chemical compound of two elements, it will be understood that the properties of air are a sort of cross between the properties of oxygen and those of nitrogen. Both these gases are without colour or smell, but in their chemical behaviour they are widely different. Oxygen is a very active element, eager to enter into chemical combination with all sorts of bodies, and its power of supporting life is simply one phase of its activity. Nitrogen, on the other hand, is a neutral, sluggish, and inert gas, without any ambitions in the direction of chemical union. This being so, it is not surprising that air acts like diluted oxygen, the nitrogen, as it were, chilling the enthusiasms of the more active gas. Many things burn in air—that is, they combine chemically with the oxygen which it contains—but the combustion is

much more vigorous when pure, undiluted oxygen is supplied. The process of respiration is very similar to the process of combustion, and it will be remembered that in cases of serious illness, and as a last resort, pure oxygen is sometimes supplied to the patient instead of air, in order to support for a little longer the flickering flame of life. A little chip of wood serves very well to show the difference between pure nitrogen, pure oxygen, and the air which is a mixture of both. If the chip is set alight and is then blown out, it continues to glow in the air for some considerable time. When the still glowing chip is thrust into a jar of pure oxygen it at once bursts into flame, whereas if it were thrust into a jar of pure nitrogen it would be immediately and completely extinguished. So we learn that of the two chief constituents of atmospheric air one supports combustion, the other does not.

Besides oxygen and nitrogen, there are a number of other gases in the atmosphere, but only in very small amounts. The chief of these are argon, a gas resembling nitrogen, to the extent of 9 volumes in 1000 of air, water vapour in varying amount, and carbon dioxide to the extent of 3 or 4 volumes in 10,000. The last-mentioned gas is being constantly produced by the combustion of all sorts of fuel, and in the respiration of animals. Whereas the air which we take into our lungs contains, as has just been said, ·03 or ·04 per cent. of carbon dioxide, expired air contains as much as 3 to 5 per cent. of carbon dioxide and correspondingly less oxygen. Strange to say, this constant enormous production of carbon dioxide does not lead to any increase in the average amount of that gas in the atmosphere, for it is as constantly being removed by the instrumentality of

the vegetable world. The green leaves of plants, aided by sunlight, have the power of decomposing carbon dioxide, liberating the oxygen, and using the carbon for their own consumption. In regard, therefore, to the production and consumption of carbon dioxide, the animal and vegetable kingdoms are complementary to each other.

To the ordinary person it may appear rather a difficult matter to detect the presence of these odourless, invisible gases, but the chemist has discovered ready methods of recognising and distinguishing them. The properties of each gas have been carefully studied, and in almost all cases substances have been found which will behave in some characteristic manner when a particular gas is present, and remain unaffected when that gas is absent. One of these useful substances, employed to test for the presence of carbon dioxide, is lime water. When slaked lime is shaken with water, a little of it dissolves, the water becomes slightly alkaline, and the clear part free from sediment is known as lime water. Now when a mixture of gases containing carbon dioxide is shaken with lime water, or is bubbled through the lime water, the latter becomes quite cloudy, owing to the formation of chalk. No other gas behaves towards lime water in this peculiar manner, so that we are able to obtain visible proof of the presence of a gas which is itself quite invisible.

It is sometimes very necessary to be able to detect the presence of carbon dioxide; for although the gas is not actively poisonous, yet it does not support life, and its presence in large quantity is very harmful. In all processes of fermentation, as, for example, in the brewing of beer, large quantities of carbon dioxide are produced. Further, this gas, being considerably heavier than air, has a habit of accumulating at the bottom of vessels and

forming what may be regarded as invisible pools. Hence it has occasionally happened that a brewery worker, descending into one of the large vats for the purpose of cleaning it, has collapsed fatally—practically drowned in the carbon dioxide which had collected at the bottom of the vat. When a descent has to be made either into a brewer's vat, or into an old well, where a similar accumulation of carbon dioxide may occur, a lighted candle ought first to be lowered to the bottom. Should the candle continue to burn as brightly as in the open air, no one need hesitate to follow it. If the candle, however, goes out, or even gets dim only, it is evidence that there is a dangerously large quantity of carbon dioxide present.

The element carbon combines with oxygen in more than one proportion, giving rise not only to carbon dioxide, but also to carbon monoxide. This latter substance is a colourless and odourless gas, which burns with a blue flame and is intensely poisonous. Any one who watches a clear coal fire on a winter evening will notice little tongues of blue flame; these are due to carbon monoxide, which readily combines with more oxygen to form carbon dioxide. Carbon monoxide has a curious effect on the blood—an effect which is directly associated with its poisonous properties. It has the power of forming a compound with the haemoglobin, the colouring matter of the blood, and this involves a slight change of tint. By shaking up the suspected gas with a little blood, and then comparing the latter with some of the original blood, either by mere inspection or by means of a spectroscope, one may detect quite small quantities of carbon monoxide.

Some very interesting cases are on record in which mice have been used to indicate the presence of carbon monoxide in an atmosphere. Small animals, such as mice, are

affected by this poisonous gas more rapidly than human beings, and the behaviour of mice therefore serves to give warning of its presence in dangerous proportions. After the Snaefell Mine disaster in 1897, for instance, the rescue party, headed by Professor Le Neve Foster, descended ladder after ladder in the shaft only after a mouse had been previously let down to the next lower level. A lighted candle also was attached to the cage containing the mouse. "By the aid of this testing apparatus," says Professor Foster in his Report, "it was easily ascertained without any risk that the air was not bad as far as the 115 fathoms level, and that it became poisonous and deadly at the 130. The mice showed precisely the same symptoms as human beings; for, if not completely dead on arriving at the surface, they had lost all power in their legs, whilst pinkness in the snout recalled the pink lips of the dead bodies of the unfortunate miners."

Until recently it was the regular custom to carry a couple of white mice on every submarine boat, the object being the detection of any carbon monoxide which might be produced by imperfect combustion of the gasolene. It appears, however, that mice are not sufficiently sensitive to small quantities of the gas, and the practice of carrying them on submarines is now quite rare.

The question may have occurred to the reader—how does it come about that gases, while obeying the fundamental laws of matter in many respects, are yet so utterly different from the more compact forms of matter with which we are acquainted—namely, liquids and solids? It is not only that gases are frequently invisible, but they are peculiar also in their ability to occupy fully any space that is offered to them. If a quantity of gas which fills a ten-gallon gasometer is

transferred to one holding twenty gallons, the gas will occupy every corner of the latter. There is, of course, less of it at any particular point, and its total weight remains the same, but its distribution is carried to the utmost limits of the containing vessel, however large that may be. A moment's thought will show how different this is from the case of a liquid such as water. Ten gallons of water remain ten gallons whether the containing cistern holds ten, twenty, or a hundred gallons. Gases, then, are distinguished from liquids by their remarkable expansibility and compressibility. The space or volume which a given quantity of gas occupies depends altogether on the pressure to which it is subjected, and the very simple law has been discovered that the volume of a gas diminishes in the same proportion as the pressure increases; that is, when the pressure is doubled, the volume is halved; when the pressure is trebled, the volume is one-third of what it was originally, and so on.

The volume of a gas is further very sensitive to changes of temperature, and it has been found that a gas which occupies ten gallons at 32° Fahrenheit will occupy between thirteen and fourteen gallons at 212° Fahrenheit, provided the pressure has remained the same. This behaviour, again, is quite different from that exhibited by liquids. Everybody knows that a pint of water does not become noticeably more bulky when it is raised to boiling. As a matter of fact, it does expand, but the expansion is too slight to be detected by the eye.

These striking differences between gases and liquids were, of course, obvious to our scientific forefathers, and some generations ago they adopted the explanation which

still holds the field. We first assume the atomic nature of matter; that is, we suppose that if we had a microscope powerful enough, we should find that an apparently continuous and homogeneous piece of matter is really discontinuous, consisting ultimately of tiny, separate, and distinct specks or molecules, just as what looks like a single homogeneous black mound in the distance may turn out on closer inspection to be a heap of separate cannon balls. Then we suppose further (and this seems very unlikely at first) that in the case of a liquid or a gas the ultimate particles are in a state of continual motion. The particles or molecules of a gas are to be pictured as rushing hither and thither at a very high speed, constantly colliding with one another and with the walls of the containing vessel. The pressure which the gas exerts on the walls of the containing vessel—a pressure which we may easily measure—is due simply to the impacts delivered by the myriads of moving molecules. Each molecule, as it comes up to the wall of the containing vessel, delivers its blow, and rebounds with undiminished speed, to continue its zig-zag course among the other molecules. If part of the wall of the containing vessel is removed, then the molecules immediately rush ahead and occupy whatever space is offered to the gas.

Although the picture just outlined of the conditions which prevail in a gas may seem somewhat improbable to the reader, it has been found capable of giving an excellent interpretation of the varied behaviour of gases. But that is another story, and would lead us too far.

The molecules of a gas are very small compared with the spaces between them. When it is remembered that the molecules in a volume of gas about the size of a

pin head are thirty million times as numerous as the human beings on the face of the globe, it will be seen that a gas molecule is quite the smallest thing we can think of. Not less surprising than the size of the molecules is the rate at which they move. If it came to a race between an express train and a molecule of oxygen, the train would be hopelessly out of it; for the oxygen molecule slips along at the rate of about twenty miles a minute.

Now why should liquids be so different from gases, so much more easily visible, so much more tangible, so much less changeable in their volume? The key to the difficulty lies in the recognition that in a liquid the molecules are much closer together than in a gas. Just as one heavenly body attracts another, so a molecule is subject to the attractive force of the surrounding molecules, and it is only because the molecules of a gas are *relatively* so far away from each other that the attraction may be neglected in this case. In a liquid, however, where the molecules, although still endowed with the power of rapid motion, exert a powerful attraction on each other, it becomes very difficult for an individual molecule to escape through the surface of the liquid. There is, as it were, a social force exerted which seeks to prevent the individual molecule deserting the community. Those molecules which attempt to escape through the surface with a rush and so evaporate have to run the gauntlet of the crowded molecules around, and most of them are prevented. Thus it comes that a liquid is not at liberty to expand to any extent like a gas; a liquid has a definite volume, whereas a gas, like the Vicar of Bray, adapts itself to suit the circumstances in quite a remarkable manner.

CHAPTER V

ELEMENTS WITH A DOUBLE IDENTITY

IN the study of chemistry one constantly encounters puzzling phenomena, the interpretation of which involves much patient labour on the part of the investigator. One of these puzzling things is the fact that some substances which are undoubtedly elements have a way of appearing in different forms according to the circumstances under which they are produced. We know that an actor plays sometimes one part, sometimes another; but although his get-up differs from time to time, it is always the same man underneath. So an element may be found masquerading in the garb of strange, unwonted properties, which are apt to deceive the onlooker, and it is one of the triumphs of chemical science that by its penetrating methods it has been able to identify a given kind of matter however it may be masked.

To begin with, it is found that some substances are like the chameleon, which can change the colour of its skin, or like the mountain hare, whose fur is brown in summer and white in winter. Such substances exist in two forms of different colour. It is not only in regard to colour, however, that the two modifications differ; their other properties are quite distinct also. A good illustration of this is furnished by phosphorus, which was referred to in a previous chapter as one of the elements which occur in nature always in a state of combination, and

never free. Phosphorus, however, can be extracted from bone ash by certain processes, and when prepared in this way it is a yellowish-white, waxy solid which can be cut with a knife. It has to be kept under water, for if exposed to the air it combines with the oxygen and is gradually converted into a compound of phosphorus and oxygen.

Phosphorus is very easily melted, and if the water under which it is kept is raised to a temperature a little above blood heat, the phosphorus becomes a liquid. It takes fire with the greatest readiness, and if, instead of being melted under water, a piece of phosphorus is heated in the air, it will ignite at a temperature very little above its melting-point.

In the dark a lump of phosphorus exhibits a curious glow or phosphorescence, which is directly connected with the action of the oxygen in the air upon it. From what has been said it will be understood that phosphorus is not dissolved by water, but there is one liquid which dissolves large quantities of the element, namely, carbon disulphide. On this property a pretty experiment can be based, for if a little of the solution of phosphorus in carbon disulphide is poured on blotting-paper, the finely-divided phosphorus which is left after the evaporation of the carbon disulphide takes fire spontaneously.

Ordinary phosphorus is further extremely poisonous, and many cases have occurred in which children have been poisoned by sucking the ends of matches, in the preparation of which phosphorus is used.

Let the reader now draw a mental picture of this yellowish-white, waxy solid, easily melted and readily set on fire, very poisonous and giving a characteristic phosphorescence in the dark, and put side by side with

it the picture of another substance with the following different characteristics:—a red powder which cannot be melted, which can be heated in the open air to a temperature of 450° Fahrenheit without taking fire, which does not phosphoresce in the dark, is not poisonous, and not soluble in carbon disulphide.

Nobody looking casually at these two substances would dream of regarding them as anything else than quite separate and distinct. And yet the fact is they are both the same element—phosphorus. The chemist has learned how to convert the ordinary yellow phosphorus into the red, and how the reverse change of the red into the yellow may be effected. Besides, the compounds which are prepared from the red variety are exactly the same as those obtained from the yellow form, so that there is no doubt that phosphorus is an element with a double identity.

How is it that a given element is able to assume different characteristics? How is it that such totally distinct properties can be associated with one and the same kind of matter? There are two possible causes for this curious phenomenon, and if we build on the foundation already laid in a previous chapter, we may be able to make the explanation clear.

It was said there that the smallest particles of a substance which can exist by themselves are called molecules, each of these containing one or more atoms. In the case of an element the atoms which go to make up the molecule are certainly all of one kind, but a further question arises about the number. And the first possible cause of the phenomenon that an element exists in two absolutely different forms, like red and yellow phosphorus, is simply this, that the molecules in the two cases contain

a different number of atoms. Since we are dealing with one and the same element, the atoms in the two cases must be the same in kind, but there may be more of them in the one case than in the other.

There is, however, another possible explanation. We must remember that not only are atoms grouped to form molecules, but molecules are massed together to form the substance as it presents itself to our eyes. If the hordes of molecules are arranged in regular fashion, then we get a crystalline substance; if they are arranged anyhow, we get an amorphous substance—that is, one without form. So with phosphorus, the molecules may be marshalled differently in the two varieties.

Of the two explanations which may thus be given for the existence of phosphorus in two distinct forms, the latter is the more probable. Red or amorphous phosphorus differs from yellow phosphorus, not in having a different number of atoms in the molecule, but in that the molecules are arranged differently in the two cases.

A most interesting and more familiar example of an element occurring in different forms is furnished by carbon. There are no less than three modifications of this element, two of which at least are as the poles asunder in respect of outward appearance and commercial value. It is indeed difficult to realise that dull, amorphous carbon, in the forms of charcoal or lampblack, is the same element as the brilliant, flashing diamond. Yet so it is; while, in addition to these two modifications of carbon, there is a third, quite distinct from both, and variously known as graphite, black-lead, or plumbago. Graphite is a little more distinguished-looking than charcoal, but is mean and commonplace in comparison with the diamond. The three forms of carbon, however, differ not

only in outward appearance, but in the value we set on them and in the uses to which they are put.

The diamond is very highly prized as a gem, and fetches in the market far more than its weight in gold. All real diamonds which the reader has ever seen have been obtained from natural sources; and diamond mining is a regular form of enterprise.

Many attempts have been made in recent times to manufacture diamonds, reminding one of the efforts of alchemists to convert lead into gold. Reflection, however, shows that these modern attempts are considerably less ambitious. Their aim is, not to change one element into another, but to convert one form of a given element into another form. The forms of carbon other than the diamond are easily obtainable, and the endeavour to change some of this plentiful material into a more valuable article is very natural.

More than that, the attempt to manufacture diamonds has been actually successful from the scientific and laboratory point of view, although not from a commercial standpoint. Moissan, the French chemist, working on the idea that diamonds are carbon which has been crystallised under great pressure, dissolved amorphous carbon in a crucible containing molten iron, heated the crucible in the electric furnace, and cooled it suddenly by plunging into molten lead. The temperature of molten lead is very much lower than that of molten iron, so that the outside portions of the latter in the crucible solidified immediately. As the iron inside this crust gradually solidified, enormous pressure was produced; for iron, like water, expands when it passes from the liquid to the solid state. The carbon, therefore, which was dissolved in the iron crystallised out under great pressure.

Fragments of diamond were obtained in this way, too small, however, to be of any value as gems.

Although it is so difficult a matter to obtain even very small diamonds from charcoal or graphite, the reverse change can be quite simply effected. If a diamond is strongly heated it becomes more bulky and is converted into something that resembles coke or graphite; that is, it loses all the special crystalline character to which the diamond owes its brilliancy.

The reader must bear in mind the distinction between artificial and imitation diamonds. Such artificial diamonds as were made by Moissan were the real article, and were found to consist of carbon. Imitation diamonds, on the other hand, contain no carbon; they consist of a soft, heavy flint-glass, known by the curious name of "paste." One interesting way of distinguishing real from imitation diamonds is to bring them close to a little radium salt in a dark room; under this stimulus the real diamond phosphoresces, but the imitation article makes no response.

The diamond is not only ornamental; it has many practical uses as well. One of the most remarkable things about it is its extraordinary hardness, in virtue of which it can scratch even a piece of hardened steel. With a fragment of a diamond fitted in a stem it is possible to write on glass as with a pen on paper, and with the natural edge of a small diamond crystal one can make a cut in a glass plate, so that the latter can be broken off like a piece of wood which has been nearly sawn through. The hardness of the diamond accounts also for its great usefulness in rock-boring tools; with a diamond drill, that is, a steel cylinder round the edge of which is fixed a series of diamonds, the hardest rocks can be gradually

pierced. In polishing a diamond the only material which is of any use is diamond dust; even emery is too soft to touch it. The phrase "diamond cut diamond" has its explanation in what has just been said.

Graphite, or black-lead, as it is commonly called, is easily distinguished from the diamond; it is a greyish black substance, crystalline certainly, but soft and soapy to the touch. People gave the name of "black-lead" to this form of carbon because they were under the mistaken impression that it contained lead. The power of graphite to give a mark on paper, a property which has found application in the manufacture of pencils, is exhibited also by metallic lead, hence the really erroneous name of "black-lead."

There are many other ways in which graphite is usefully applied besides the manufacture of pencils. It is scarcely affected at all by exposure to great heat, and is accordingly made up along with clay into crucibles for use at high temperatures. Then it is used to coat ironwork—grates, for example—in order to protect it from rusting, and at the same time to give it a shiny appearance. Another curious use to which graphite is put is the lubricating of machinery working at a high temperature, at which ordinary oil would be unsuitable.

Whereas diamond and graphite occur naturally, the various forms of amorphous carbon are generally obtained as the products of human operations. Thus wood charcoal is got by the partial combustion of wood, lampblack is the product of the imperfect combustion of oil, while animal charcoal is obtained by heating bones very strongly. Wood charcoal, lampblack, and animal charcoal or boneblack all consist of amorphous carbon, and are applied in many useful and interesting ways.

One of the main characteristics of wood charcoal is its power of absorbing gases in large quantities, a property which renders it of value in the purification of bad air. By passage through charcoal filters sewer gases and other noxious emanations may be rendered harmless. Bone-black, again, has a remarkable power of removing colouring matter from liquids, such as red wine or indigo solution; it is accordingly employed very extensively in decolourising sugar during the process of refining. Lamp-black, on the other hand, is applied for quite different purposes. It is useful as an artist's pigment in both oils and water colours, and forms the chief ingredient of Indian ink and printing ink.

The uses to which carbon in its various forms may be put are, in fact, legion, and in the face of these it is necessary to re-emphasise the fact that diamond, black-lead, and charcoal are all modifications of this one element. The fundamental experiments on which this statement is based were carried out more than a century ago. Before this, people were in great doubt about the exact nature of the diamond, but it was then shown that, starting with a given weight of either diamond, graphite, or charcoal, one obtained in all three cases the same weight of the gas carbon dioxide, and nothing else besides. This experiment proved incontestably that diamond, graphite, and charcoal are merely different forms of one and the same element.

The explanation which was given for the existence of two modifications of phosphorus is valid also in the case of carbon. Diamond, graphite, and charcoal differ, not in the number of atoms contained in the molecule, but in the arrangement of the molecules to form the substance as it appears to our eyes.

There is, however, one notable illustration of an element existing in two forms which differ in respect of the number of atoms in the molecule. That is the common element oxygen. The molecule of this gas contains two atoms, but under certain circumstances it is possible to induce three atoms of oxygen to club together in a molecule, and then we have ozone. Long before anybody knew about this curious substance, a peculiar smell had been noticed whenever an electrical machine was at work, and people adopted what seemed the simplest explanation and regarded it as the "smell of electricity." We now know that an electrical discharge, either as a spark from an induction coil, or in the shape of lightning, converts some of the oxygen in the air into another substance, ozone, which is responsible for this peculiar smell.

To speak of ozone as "another substance" is both right and wrong. It is right because, in regard to the properties which it possesses, ozone is quite distinct from oxygen. In some respects it behaves like intensified oxygen, oxidising things which that gas cannot touch. An illustration of this is the extraordinary effect which it has on mercury. The merest trace of ozone introduced into a vessel containing the metal seems to scare it out of its usual behaviour; the bright, lustrous surface becomes dull and unresponsive; instead of moving about freely, it sticks to the glass as if it were greased.

In a second sense it is wrong to speak of ozone as "another substance" than oxygen, for they are simply two forms of the same element—"allotropic" forms, as the chemist calls them. (The existence of phosphorus and carbon in more than one modification was attributed to a different arrangement of the molecules, but such an explanation could not possibly be correct in the case of

gases like oxygen and ozone. For, as has been pointed out already, the molecules of a gas are rushing hither and thither at a high speed, and any definite arrangement of these particles is quite out of the question.)

The few cases discussed in this chapter of elements existing in more than one form are simply illustrations of what has been observed all over the field of chemistry. It is very frequently found that two compound substances with the same chemical composition are quite distinct in their outward appearance and general behaviour. In some instances the difference is merely one of crystalline form, and is to be attributed to a different arrangement of the molecules. In other compounds, however, the origin of the distinction is far more subtle, and is found in a different arrangement of the atoms within the molecule. The story of the way in which chemists have discovered the internal structure and anatomy of the molecule is very fascinating, but it is long and intricate, and would detain us from excursions into interesting fields which are close at hand.

One other curious phenomenon, however, deserves notice here. (When a compound exists in two crystalline modifications, it is very commonly observed that one of the forms has but little persistence, and changes into the other on the slightest provocation. Some years ago the writer came across an interesting case of this kind. He obtained a substance which crystallised in the form of shiny leaflets, but these were no sooner produced than they began to change, entirely of their own accord, into little needle-shaped crystals. The first form of the substance, in fact, never existed for more than a few minutes.

A host of similar interesting cases might be quoted

but enough perhaps has been said to convince the reader that the study of the various forms in which an element or compound can exist reveals Nature in very curious moods, and brings the chemist into touch with some of the most interesting problems of matter.

CHAPTER VI

METALS, COMMON AND UNCOMMON

NO one can fail to notice that metals and alloys play a very important part in the economy of modern life. It has not always been so in the history of the world, for, "as every schoolboy knows," there was a time when tools and weapons were made exclusively of stone. That primitive stage in man's conquest of nature was followed by the Bronze Age and the Iron Age, and ultimately, when Greece and Rome were at the height of their glory, as many as seven metals were known and utilised. At the present time the number of known metals is very much greater, and innumerable alloys, made by mixing two or more metals, find application in our technical and social life. We see them everywhere, from powerful engines and gigantic bridges down to needles and pins; we carry them about with us, on our boots, in our pockets, on our fingers, in our hair, and sometimes even in our mouths.

The majority of the seventy known elements are metals, and among these there are all sorts and conditions. Only one is a liquid—mercury or quicksilver—and its curious combination of the properties of a metal and those of a liquid render it useful for many special purposes. In the same way, however, as liquid water may be converted into steam by heating and into ice by cooling, so the liquid metal may be boiled, producing mercury vapour, or it may be

solidified by the application of cold. Indeed, during winter in extremely cold countries like Siberia the mercury in the bulbs of the thermometers may be frozen; this happens when the temperature falls 40° below zero Fahrenheit.

Metals exhibit great variety of density, and it must not be supposed that a metal is necessarily a heavy substance. It is true that mercury is nearly fourteen times as heavy as water, and that gold is about nineteen times as heavy, yet there are metals—sodium, for instance—which are lighter than water; if a piece of this metal is thrown on water it swims about on the surface. The reader may remember aluminium as a comparatively light metal, the weight of which, bulk for bulk, is only one-seventh of that of gold.

Only a few of the metals are found in the uncombined or "native" condition. These are the so-called "noble" metals—gold, platinum, &c.—which are distinguished by the fact that they do not tarnish, and are not readily attacked by acids. Other metals occur in the form of ores, and have to be extracted from these by laborious processes. However it has come about, the majority of the metals have combined with oxygen or sulphur, and their ores consist therefore mainly of oxides or sulphides, mixed naturally with a smaller or greater amount of earthy matter. The operations or metallurgical processes necessary for winning metals from their ores are modified by the idiosyncrasies of the particular metal which is sought, but the essential chemical reaction involved is generally the removal of oxygen from the ore by the agency of carbon. If the ore does not already consist of the oxide, the latter is obtained by roasting the sulphide in a current of air, by which process the sulphur in the sulphide is replaced by oxygen.

The oxide is mixed with coke, which contains a high proportion of carbon and the mixture is heated in a furnace, a "flux," such as lime, being added to remove the earthy matter from the ore in a fluid form. At the high temperature of the furnace the carbon in the coke deprives the metal of its oxygen and carries it off in the form of carbon monoxide or carbon dioxide. The metal is thus obtained in the free state, and is generally run out of the furnace in a molten condition, while the earthy material that was in the ore is separated along with the flux as slag.

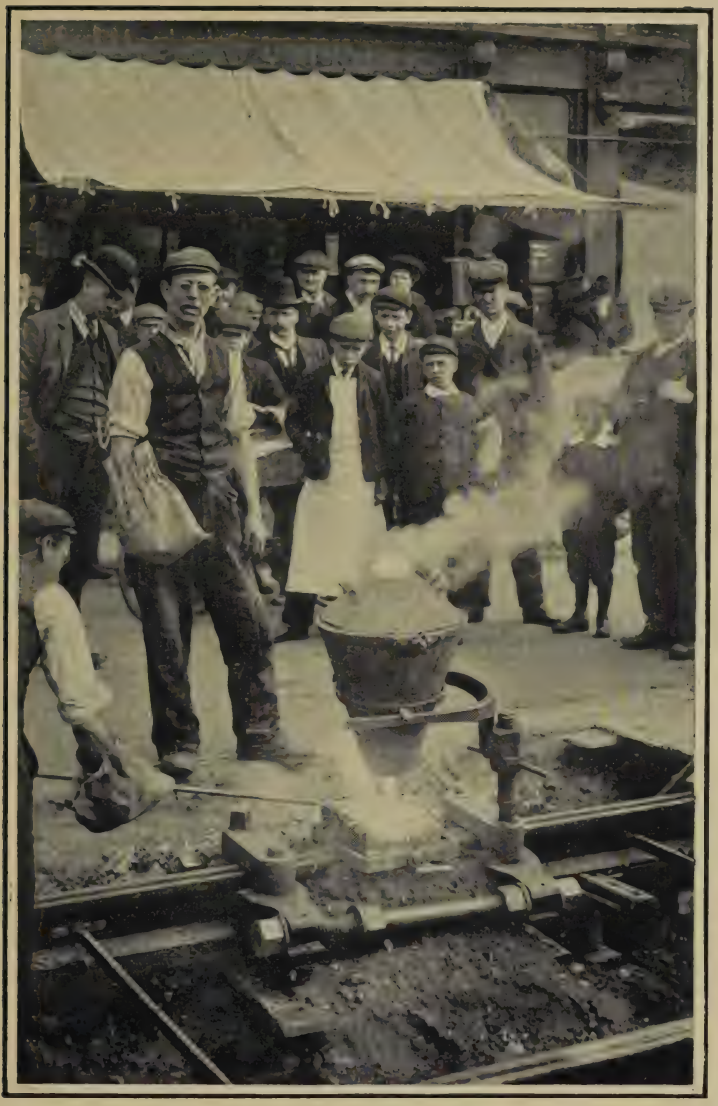
Perhaps the commonest example of such a metallurgical operation is iron-smelting, a process which may be seen at work in many parts of Great Britain. In the case of iron it is desirable to inform ourselves a little more about what is done with the crude metal obtained from the blast furnace, and it is well that we should understand the chemical differences between the various kinds of iron which are of technical importance, namely, cast-iron, wrought-iron, and steel. The different properties which characterise these varieties of the metal show in a very interesting manner how the behaviour of a pure substance is modified by the presence of small quantities of foreign matter.

In a description, given in an earlier chapter, of the attempts which have been made to manufacture diamonds, it was said that molten iron dissolves carbon. Since now in the process of iron-smelting the fused metal has been in contact with coke in the furnace, it is not surprising that the crude metal which is taken out of the furnace contains an appreciable amount of carbon, as much as 3 to 5 per cent.; it is run into moulds, and is then known as cast or pig-iron. Careful examination has shown that

of the total carbon present in cast-iron some has combined with the metal to form a compound known as a carbide, while the rest has crystallised out during cooling in the form of graphite.

If the carbon is removed from cast-iron as completely as possible we get wrought-iron, which contains only about one-tenth of 1 per cent. of carbon, and differs very notably in its properties from cast-iron. In the first place, wrought-iron can be welded—that is, if two pieces of this material are made red-hot they soften, and in this state may be hammered together. This cannot be done with cast-iron, which is a hard, brittle, crystalline substance.

Again, cast-iron is much more easily melted than wrought-iron. The latter is very nearly pure metal, whereas the former contains an appreciable quantity of foreign material. Now it is a well-known fact that if a small quantity of a foreign body is added to a pure substance, the melting-point of the mixture is lower than that of the pure substance. Salt water, for example, contains much more dissolved matter than fresh water, and is more difficult to freeze; or, to put it the other way round, ice melts at a lower temperature in salt water than it does in fresh; in fact, a strong solution of common salt in water will not freeze even at 0° Fahrenheit. The fact that cast-iron melts more easily or has a lower freezing-point than wrought-iron is therefore an illustration of a very general principle. The reader will observe that the freezing and melting-points are to be regarded as the same temperature, and this is always so if we are dealing with a pure substance. The difference is merely this, that if we are thinking of the solid being converted into liquid, the



MOLTEN IRON WITHOUT A FURNACE

The crucible is charged with a mixture of metallic aluminium and iron oxide, known as "thermit," and the mixture is ignited. Chemical action sets in, which results in the formation of metallic iron and aluminium oxide, and the heat generated is so intense that the iron is melted. As shown in the illustration, the molten iron may be used for welding tram rails. The heat of the chemical action is so great that the eyes of the operators have to be protected by darkened glasses.

temperature at which this takes place is called the melting-point; if, on the other hand, we are thinking of the change of liquid into solid, the temperature at which this change occurs is called the freezing-point. The two temperatures are the same if the substance is pure.

The third variety of iron, namely, steel, is intermediate between cast and wrought-iron in regard to the amount of carbon which it contains. The remarkable thing about steel is that when it is heated and then suddenly cooled by plunging into cold water it becomes exceedingly hard, so much so that it has the power of scratching glass. Curiously enough, if this hard steel is again heated and then allowed to cool *slowly*, it is found to be nearly as soft as ordinary iron. By regulating the temperature to which the hardened steel is exposed the second time, any required degree of hardness may be attained. Articles made of steel, such as razors, scissors, and watch-springs, are therefore first hardened, and then "tempered" by heating them to a point between 430° and 550° Fahrenheit, the temperature varying according to the purpose for which the article is to be used. A razor, for example, is heated only to 430°, a temperature at which the metal acquires superficially a pale yellow colour, due to the formation of a film of oxide. Watch-springs or sword-blades, on the other hand, which should be softer and more elastic, are tempered by heating to 550°, and the colour of the surface film passes through various shades—yellow, brown, purple, and blue—as the temperature rises. The degree of heat attained in tempering may in fact be judged from the colour of the surface. Thus hardened steel which has been heated to 430°, and then

allowed to cool slowly, is said to be "tempered to the yellow," and is hard enough to take a fine cutting edge. It must be remembered that steel which has been hardened without being tempered is of no use for ordinary purposes; it is too brittle.

It is many centuries now since man first began to discover the valuable properties of iron, and the passage of time has only led to a gradually widened range of application, and to improved methods of production. One can name metals, however, which for a long time after their discovery were regarded as curiosities, and have only recently and more or less suddenly been in large demand as their useful properties have been realised. Aluminium is a notable example of this. Fifty or sixty years ago it cost twenty shillings an ounce; now it can be purchased for less than a shilling a pound. The very high price of the metal was due, not to scarcity of material from which aluminium could be produced, but to the fact that there was little or no demand for it, and no satisfactory method of extracting it from its ores.

As a matter of fact, aluminium is one of the most common constituents of the earth's crust, occurring in the combined state as mica, felspar, clay, and slate. It is in many respects a remarkable metal. It is exceedingly light, and yet, unlike most other metals of this class, is not easily tarnished even in the presence of moisture. On account of its lightness it is extensively used in military fittings, while its resistance to the action of animal and vegetable juices renders it serviceable in the manufacture of cooking utensils.

Although aluminium in the mass is not easily oxidised in air, probably because it gets coated with a thin film of

oxide which acts as a protective layer, the powdered metal burns vigorously, like magnesium, when it is heated, and in this way a very high temperature is produced. If the oxygen which is necessary for the combustion of the aluminium is mixed with the metal at the start, instead of coming from the air as the burning proceeds, an even higher temperature can be reached. But how, the reader may ask, can we mix a gas with a solid? In the literal sense, certainly, this cannot be done, for to burn half an ounce of aluminium powder as much as fifteen pints of oxygen gas would be required. But the oxygen may be mixed with the aluminium in a compact or condensed condition in the form of some compound, out of which the aluminium has no difficulty in extracting it.

Iron oxide is such a compound, so if a mixture of powdered aluminium and iron oxide, known as "thermit," is ignited at one point an action sets in which spreads through the whole mass, giving out intense heat, and resulting in the formation of aluminium oxide and molten metallic iron. The aluminium, in fact, feeds on the oxygen of which it has deprived the iron. The heat produced in this competition for the oxygen is so intense that if some thermit mixture is placed on an iron plate half an inch thick, and ignited, a hole is melted in the plate.

The heat stored up in thermit may, however, be turned to more practical account in the following interesting manner:—If the ends of two steel rails are pressed together and some of the intensely hot fluid iron produced in the thermit reaction is run out of a crucible on to the junction, the crevices are filled, the heat is such that the ends of the rails are softened, and may be welded by the applied pressure so that a sound joint is made. In a

similar way thermit may be employed for repairing iron shafts and pipes.

In aluminium we have an example of a metal the price of which has fallen in a remarkable manner, not because fresh sources of the metal have been discovered, but because the increased demand has led to cheaper and more efficient methods of production. There are other metals, however, which are costly, not because there is any difficulty about their extraction, but because the natural supply is limited.

Platinum is a case in point. Endowed with unique and valuable properties, it is comparatively rare, and possibly the reader has never seen a specimen; it costs nearly twice as much as gold. Platinum is a silvery metal, twenty-one times as heavy as water, bulk for bulk, and does not rust or tarnish. Like gold, it is a "noble" metal, and is not dissolved by any single acid which we know, not even by *aqua fortis* (nitric acid). A mixture of nitric and hydrochloric acids, however, will dissolve both platinum and gold, and it was the power of this mixture to attack the latter metal which led the alchemists to speak of it as "*aqua regia.*"

Platinum is in a special sense the chemist's metal. Its very high melting-point — 3200° Fahrenheit — and its chemical inertness make it valuable to him, and platinum crucibles are to be reckoned among the indispensables of a properly-equipped chemical laboratory.

There is another characteristic of platinum which to the casual reader may seem most insignificant, but which, as it turns out, is of the greatest importance in a certain manufacture. This is the fact that with rising temperature platinum expands at nearly the same rate as glass. Why should that be of any consequence? the

reader may ask, and what has platinum got to do with glass? Well, it is generally recognised that bodies expand when heated—they become more bulky as the temperature rises. As a rule, the expansion differs with different substances, but it so happens that platinum expands to the same extent as glass for a given rise of temperature.

We may realise the significance of this fact when we remember that it is sometimes necessary to pass a metal wire through the walls of a glass vessel. This has to be done, for example, in the electric glow lamp, the illuminating power of which is due to a carbon filament raised to a white heat by the passage of an electric current. As the carbon would soon burn away if it were surrounded by air, the little glass globe which protects the filament must be freed from air and then sealed up. The wires, therefore, which carry the current must pass through the walls of the globe, and the question at once arises, what metal should be used for these wires?

Copper, the metal which is so commonly used for electric wiring, would be quite unsuitable, because it does not expand and contract with change of temperature at the same rate as glass. If we passed a copper wire through a piece of glass while the latter is hot and soft, and melted the glass all round the wire, then on cooling, owing to the unequal contraction of the metal and the glass, a condition of strain would be produced, leading finally to the fracture of the glass.

A metal is required which expands and contracts at the same rate as glass, and the one metal with this characteristic is platinum. Hence it comes that an electric glow lamp has two little pieces of platinum

connecting the ends of the filament inside with the terminals outside.

Thus it is that what may seem at first to be nothing more than a dry laboratory fact, without any practical bearing, may turn out to be of the greatest importance for the requirements of everyday life.

Such a case of the discovery of a new use for a metal, and a consequent fresh demand for it, might be paralleled by what has happened recently in connection with tantalum. This is a rare metal, and up to within a year or two ago very little attention had been paid to it, as a glance at any chemical text-book will show. It has been discovered, however, that tantalum has certain properties of commercial value, and people are now on the look-out for fresh sources of this somewhat scarce material.

The illuminating power of the electric glow lamp depends, as has been said already, on a carbon filament being raised to incandescence by an electric current. Now these carbon filaments are very fragile creations, and one might at first be inclined to wonder why fine metallic wires are not used instead; for it is well known that a metallic wire is similarly heated by the passage of a current. The explanation is simple; in order to get a respectable light from an incandescent metal wire, we should have to raise it to a temperature at which it would melt. This would happen even with platinum, for the temperature of the carbon filament in an electric glow lamp is several hundred degrees higher than the melting-point of that metal.

It is just here that the valuable properties of tantalum come in. Briefly stated, they are these: tantalum can be drawn into very fine wire, about one-thousandth of

an inch in diameter, and its melting-point is exceedingly high, so high that the fine wire may be raised to a white heat by an electric current without melting.

The tantalum lamp, then, which is now on the market, is exactly analogous to the electric glow lamp, except that the filament is made of tantalum instead of carbon. As regards efficiency, the tantalum lamp compares favourably with the ordinary glow lamp, and it is said to have a longer life. So the time may come, if sufficient tantalum can be procured, when the carbon filament will have become merely a curiosity.

Tungsten and osmium are other out-of-the-way metals which have recently found an important application in the manufacture of electric lamps, so that tantalum is not the only competitor in the field against the carbon filament.

The application of electricity to all sorts of objects has led to extended demands for other metals than those just quoted. Copper, for instance, which offers very slight resistance to the passage of a current, is much in demand for electric wiring; enormous quantities of the metal are now devoted to this purpose. Copper enters also into the composition of many alloys—brass, bronze, and the like; but the subject of alloys is a big one, and must be reserved for another chapter.

CHAPTER VII

WHERE TWO METALS ARE BETTER THAN ONE

IN the foregoing chapter we have had illustrations of the differences exhibited by metals in regard to specific gravity and fusibility, but there are, of course, many other properties—hardness, malleability, ductility, and the like—which have to be taken into account when we are considering the suitability of a given metal for a certain purpose. Frequently it happens that the metal is suitable for the purpose in all respects save one, in which case it may be possible to correct the deficiency by adding another metal, provided at the same time that this second constituent does not detract from the valuable properties of the first. The effect of the presence of carbon in iron might be considered as an illustration of this principle, but carbon is not a metal, and the amount present is not great, so that wrought-iron, cast-iron, and steel are rather in a class by themselves.

We may make good the deficiencies of a metal by the addition of another in more than one way. It is not always necessary actually to mix the metals; we may put one on the top of the other, as in tinplate or galvanised iron. In regard to strength, durability, and cheapness, iron is an excellent material, but the weak feature about it is its liability to corrode when exposed to a moist atmosphere: it rusts.

Articles made of iron which have to be exposed to air

and moisture must therefore be protected. In the case of large structures, such as bridges, locomotives, and steamers, this is done by painting them, but with smaller and more easily-handled articles the same end is attained by coating them with a layer of another metal which is not easily corroded by the action of moist air. Tin and zinc are metals which fulfil these conditions, and they are further comparatively fusible, so that a sheet of iron may be easily coated with either by simply dipping it into a bath of the fused metal. Iron coated in this way with a layer of tin is known as tinplate; similarly treated with zinc, it is known as galvanised iron.

So that things are not always what they seem. Even the common pin is a fraud in this sense, for if we could open it out we should find brass wire in the inside, quite different from the white metal on the outside. Brass, as the reader probably knows, is a yellow alloy containing a lot of copper, and the easiest way of showing that pins contain this metal is to dissolve one in nitric acid. The pin is gradually consumed by the acid, it ultimately disappears, and a blue liquid remains, similar to what is obtained by treating a piece of pure copper in the same way. So we may conclude that there is copper in the pin. The white outside is a coating of tin; this, however, is not put on, as in tinplate, by dipping in a bath of the fused metal, but by another interesting method.

The reader may recollect that among the things that lent support to the alchemists' belief in the transmutation of metals was the observation that a piece of iron immersed in a solution containing copper acquires the appearance of copper. This little trick can be performed with other metals also, and is applied in the manufacture of pins. The brass wires which form the substance of the

pins are put in a solution containing tin, and the result is that a coating of this metal is deposited on the brass.

Such a method of depositing one metal on another is very closely related to the process of electro-plating. When an electric current is passed between two metal rods or electrodes immersed in a salt solution, the salt is decomposed and the metallic constituent is deposited on one of the electrodes. Suppose now that the solution contains a salt of silver, and that we replace the rod on which the metallic constituent is deposited by a spoon made of some alloy, then on passing the current the usual thing happens, and we get a fine, coherent deposit of silver on the spoon ; the latter is electro-plated.

In this way articles made of common metals or alloys may be plated with gold, silver, copper, or nickel. For example, we can protect steel articles, such as bicycle fittings, from atmospheric corrosion by plating them with nickel. Articles, on the other hand, which are to be used for the table or for ornament may be similarly coated with silver. Spoons and forks, for instance, are generally made of Britannia metal, an alloy containing mostly tin and antimony, or of German-silver, an alloy of copper, zinc, and nickel ; when these articles are coated with silver they are less easily attacked by acid liquids, and at the same time their appearance is improved.

Plating, after all, is a device for hiding the shortcomings of one metal by covering it with another. There is, however, a second way of making good the deficiencies of a metal, and that is by mixing it thoroughly with another of different character. In what way the properties of one metal are modified by thus alloying it with a second may be best understood from a few examples.

The ubiquitous penny piece is commonly known as "a

copper." This metal in the pure condition, however, would be too soft for the wear and tear which a coin has to undergo, and consequently 5 per cent. of foreign metal (mostly tin) is added to the pure copper in order to harden it. The curious thing is that tin itself is quite a soft metal, and yet the addition of 5 per cent. of it to pure copper produces an alloy which is much harder than copper itself.

Similarly, pure gold and silver are too soft to be used either for coins or ornaments, and for this purpose they must be hardened by the addition of another metal, generally copper. The colour of an English silver coin does not betray the presence of copper, but if a three-penny bit were dissolved in nitric acid we should get the blue solution which is characteristic of copper. Since pure silver dissolved in nitric acid gives a colourless solution, we may conclude that our silver coins contain copper; as a matter of fact, they have $7\frac{1}{2}$ per cent. of that metal.

An English gold coin is also alloyed with copper to the extent of 1 part for every 11 parts of gold. Such an alloy is described as 22 carat gold, because out of 24 parts of the alloy, 22 parts are pure gold. For ornaments other alloys are made containing less of the precious metal, and described as 18, 12, or 9 carat gold, these figures indicating that 24 parts of the alloy contain 18, 12, or 9 parts of pure gold respectively.

Another property which is altered by adding a second metal is the fusibility, and an alloy as a rule melts at a much lower temperature than one would expect from the melting-points of the constituent metals. The influence of a foreign body on the melting-point of a pure substance has already been referred to in connection with cast

and wrought-iron, but with alloys the effects are much more striking.

Common solder is a case in point. Soldering consists in joining two metals by an alloy which is more easily melted than either, and which at the same time will coalesce with each metal. Tin and lead, a mixture of which forms ordinary plumber's solder, melt at 440° and 617° Fahrenheit respectively, while the solder itself melts at 374°.

The reader may already have remarked the frequency with which tin is used either to plate or alloy with other metals, and it is in fact very seldom employed by itself. Even the so-called "tin" foil in which chocolates are wrapped contains lead, and the utensils which we call "tins" are generally iron plated with tin.

In the case of solder, as we have seen, the alloy melts at a temperature lower than the melting-point of either constituent. But of the lowering of melting-point produced by mixing far more striking examples are obtained when we take four metals to make an alloy. Lead, tin, bismuth, and cadmium melt at 617°, 440°, 514°, and 608° respectively, and yet by mixing these metals in certain proportions we can prepare an alloy which melts in hot water and is known as "fusible metal."

These easily-melted alloys are put to some curious uses; for example, in connection with fire-alarms. A quantity of fusible metal is arranged in a receptacle in such a way that when a certain temperature has been exceeded the alloy melts, and releases a spring or allows a lever to fall. By this device an electric circuit is closed and a bell is rung.

Then, again, fusible alloys play a useful part in the sprinklers which are fitted up in factories and workshops.

These consist of water-pipes led round the upper part of a room, and at intervals on the pipes there are valves secured by fusible alloy. If a fire should break out in any room fitted with such a sprinkler, the heat will melt the fusible alloy at one or more of the valves, the water will burst out, and there is a fair chance that the fire will be extinguished before it has attained very large proportions.

With such examples before us of the way in which the hardness and fusibility of a metal are altered by the addition of another, we are led up to the question—Are these alterations due to the formation of a new substance, a compound of the metals, or are they accounted for by the mere mixture of the constituents?

The difference between a mechanical mixture of two elements and the compound formed by their chemical combination has already been discussed. We must next try to decide whether the features which we generally notice in chemical action are to be observed when we make two metals into an alloy. Now it must be admitted that it is rather difficult to settle the question whether an alloy is a mixture or a compound. In some respects, it is true that the mixing of two metals resembles what takes place when two elements combine. Thus we have seen that when iron and sulphur act on each other an enormous amount of heat is liberated, and such liberation of heat very frequently accompanies chemical action. Well, a similar thing occurs when we add sodium to mercury to make an alloy (or an "amalgam," as it is called when mercury is one constituent); each addition of sodium is accompanied by a flash of light. So also when a piece of aluminium is added to fused gold, an extraordinary evolution of heat is observed,

and the molten mass is raised to incandescence. Such an occurrence may be taken as evidence that chemical combination has taken place.

Again, the colour of some alloys is markedly different from that of the constituents. Silver and zinc are both white metals, and yet they form a beautiful pink alloy. Gold and aluminium also furnish us with an illustration, for when they are mixed in certain proportions a brilliant purple alloy is obtained, quite distinct in colour from both constituents.

In spite of these examples, however, it must be said that we do not observe in the formation of alloys generally such a thorough-going change of properties as commonly results from chemical combination. The question, therefore, of mechanical mixture *v.* chemical compound is not so easily decided.

Modern investigators have tackled the problem by studying the freezing-points of alloys in their relation to the freezing-points of the constituent metals, and in the course of these investigations many interesting results have been brought to light. It is almost the invariable rule that when a little of a metal B is added to a metal A, the fused alloy begins to solidify at a lower temperature than pure A; it is said to have a lower freezing-point. As we go on adding more and more of the metal B, the alloys produced have lower and lower freezing-points. The same series of phenomena is observed when we add increasing quantities of the metal A to the pure metal B.

Suppose we try to picture these results graphically, that is, with the help of a curve. In doing this we represent the composition of the alloy by distances measured along a horizontal line, while the tempera-

tures at which the alloys freeze are represented by lengths measured vertically. This is a very common method of summarising the results of scientific investigation and of showing the way in which one quantity depends on or varies with another. An example of such a use of curves is furnished by the card which comes off an aneroid barometer at the end of a week. On this card vertical distances represent the height of

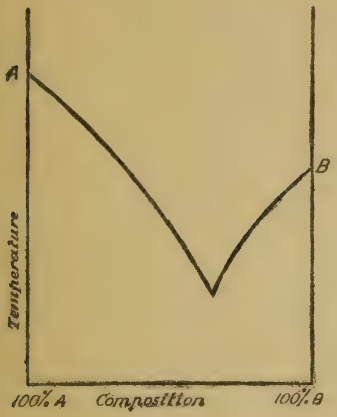


FIG. 1*a*.

FIG. 1*b*.

the barometer, and horizontal distances represent intervals of time. The curve traced on the card shows the way in which the height of the barometer has varied during the past week.

If, now, we similarly represent the way in which the freezing-point of an alloy varies with its composition, we should obtain, in many cases at least, a curve in two branches, as shown in Fig. 1*a*. Careful investigation has shown that these are the cases in which chemical combination has not taken place. The solid

which separates out when the fused alloy begins to solidify is either pure A or pure B, never a compound of the two metals.

In the cases where the two metals do form a compound, the curve showing the variation of freezing-point with composition is of a different character; there is then an intermediate branch of the freezing-point curve, shaped more or less like a camel's hump (see Fig. 1*b*). The temperature corresponding to the summit of the hump is the freezing-point of the compound which is formed, and the composition of the alloy which has this maximum freezing-point gives the composition of the compound.

It is interesting now to find that the existence of compounds of mercury and sodium, and of gold and aluminium, which we suspected from their behaviour on mixing, is confirmed by a study of the freezing-point curves for alloys of these metals. In the case of mercury and sodium the freezing-point curve has a hump the top of which is far above the freezing-point of either constituent, so that the existence of a compound is here proved very definitely.

The freezing-point curve for alloys of gold and aluminium has actually two separate humps, showing that these metals combine to form two compounds with different proportions of the constituents. One of the humps corresponds to the formation of the beautiful purple alloy already referred to, and it is very remarkable that this compound, containing 20 per cent. of aluminium, should melt at the same temperature as pure gold.

Another method of investigating the nature of alloys which has recently been employed with success is the

study of their structure with the aid of the microscope. If a section of an alloy is polished, treated with a little acid or other corrosive liquid, so as to bring out the details on the surface, and put under the microscope, one can observe an outline of crystalline structure which cannot be detected by the unaided eye. Those who have experience in this sort of investigation can actually distinguish the various kinds of crystals which have separated while the alloy was passing from the fused to the solid condition.

CHAPTER VIII

ACIDS AND ALKALIS

OF the various classes into which chemical compounds may be divided, acids form one of the largest and most important. They get their name from the sour taste which is supposed to characterise them, but this characteristic is by no means universal. From the chemist's point of view, all acids are similar in that they contain the element hydrogen, this hydrogen being replaceable by a metal. In many cases we can actually follow the replacement of the hydrogen in an acid by a metal; as, for example, when a few pieces of magnesium ribbon, iron wire, or granulated zinc are put in hydrochloric acid—"spirits of salt," as the druggist may call it. The acid and the metal attack each other, the latter disappears gradually and turns out the hydrogen, which comes bubbling off as a gas. What takes place might be expressed as follows:—metal acid → a salt + hydrogen, the salt left in solution being magnesium chloride, iron chloride, or zinc chloride, according as magnesium, iron, or zinc was the metal taken. The corrosive acid is, in a sense, destroyed by the metal, and the plumber's description of zinc chloride as "killed spirits of salt" is therefore quite to the point.

The behaviour of acids in attacking or corroding metals is very general, and even domestic illustrations are available. Vinegar is a household article, but it is well to

remember that it contains a fair quantity of acetic acid, which, although not so powerful as sulphuric or hydrochloric acid, is yet able to exhibit the corrosive action which is characteristic of acids in general. A drop of vinegar left on the surface of a copper saucepan will betray itself before long by the appearance of verdigris; this is acetate of copper, the salt produced by the action of the acetic acid in the vinegar on the copper of the saucepan.

The wit of man has hit upon methods of utilising this corrosive action of acids on metals, and if properly guided it becomes a process of engraving. Suppose we have a plate of copper on which we wish to trace some design. One simple way of doing this is to coat the plate completely with a thin film of wax or other substance which is not affected by acids, and then with a sharp steel point to scratch the required design through the wax. This means that the metal surface is exposed where the steel point has removed the wax, so that if the plate is immersed in an acid bath, say of "aqua fortis" (nitric acid), the metal is eaten away along the lines traced by the engraver. When the wax is dissolved, the metal plate is then found to bear the design intended, the depth of the lines depending on the length of time during which the plate has been left in the bath.

Such etching of metals is characteristic of acids generally, but there is another kind of etching, namely, on glass, which can be effected by one acid only—that is to say, it is a specific action. This very peculiar property is possessed by hydrofluoric acid, a compound of hydrogen and the element fluorine, which is combined with lime in the mineral fluorspar. If a piece of glass is coated with paraffin wax, and a design is traced upon this with a

sharp-pointed instrument, then on exposure to the vapour of hydrofluoric acid the glass is eaten away at the places where the wax has been removed. In this way the design traced upon the wax is reproduced on the glass, the surface, however, being deadened where the acid vapour has acted. If it is desired to etch without deadening the surface, the glass is immersed in a *solution* of hydrofluoric acid; this treatment leaves the glass polished and clear even where it has been etched.

The process of etching on glass is invaluable to the maker of scientific instruments, for it is frequently desirable to have figures marked on glass apparatus itself rather than on any scale attached to the apparatus. An "ink" is actually sold containing the ingredients necessary to produce hydrofluoric acid, and mere writing with this on a piece of glass apparatus is sufficient to leave an impression.

The constituent of glass attacked by hydrofluoric acid is silica. This is the oxide of the element silicon, and forms a very large proportion of the rocks in the earth's crust. Sand, for example, is impure silica, and the behaviour of hydrofluoric acid towards silica is well illustrated by allowing it to act on powdered sand in a leaden vessel. The sand gradually disappears, because the silicon in it forms a gaseous compound with the fluorine contained in the hydrofluoric acid. It is difficult to realise that the essential constituent of sand may be converted into a vapour, but that is what is effected by the action of the hydrofluoric acid.

Bearing in mind this corrosive action of hydrofluoric acid on glass, we see that it would be inadvisable to keep a solution of the acid in any glass vessel; as a matter of fact, it is usually sold in gutta-percha bottles.

The more powerful acids have a destructive and corrosive action not only on metals, but on many other substances also, notably on organic materials. The most outstanding in this respect is sulphuric acid or oil of vitriol, an innocent enough looking liquid, which, however, is extraordinarily destructive of animal and vegetable tissue, and requires very careful handling. If a drop of it gets on the skin and is not at once washed off, a very painful wound is produced. Occasional newspaper reports show that there are people who regard vitriol throwing as a proper way of settling old scores, but from what has been said it will be understood that it is a diabolical proceeding, and is very rightly scheduled as a crime. The destructive action of sulphuric acid on vegetable tissue is seen when a drop falls on wood. The latter turns black and has a charred appearance, just as if it had been burned.

Sulphuric acid is characterised by an extraordinary fondness for water. If cold sulphuric acid is added to cold water in a glass vessel, the warmth of their meeting is quite remarkable, and the vessel becomes too hot to hold. Further, if a dish containing a little sulphuric acid is left exposed to the air, the bulk of the liquid gradually increases, and if left long enough the dish would overflow, the reason being that the sulphuric acid absorbs from the air as much moisture as possible, and so becomes diluted. The affinity of sulphuric acid for water is much utilised by chemists in order to render gases absolutely free from moisture. A current of hydrogen which is being evolved by the action of a metal on hydrochloric acid comes off fully charged with water vapour, but if it is made to bubble through sulphuric acid, the water molecules are seized by the acid and the hydrogen is obtained dry. So

thorough is the scrutiny that scarce a single water molecule escapes.

One property characteristic of acids generally is their power to make carbonates effervesce. Here again domestic resources will be sufficient to supply us with an illustration, for most houses can furnish vinegar and washing-soda. As has been said already, vinegar contains a certain proportion of acetic acid, and washing-soda is nothing else than carbonate of soda. When, therefore, we pour a little vinegar on washing-soda we bring together an acid and a carbonate, and the result is the usual one, namely, effervescence due to the liberation of carbon dioxide.

This production of gas which occurs when an acid and a carbonate are brought together is applied very ingeniously in the chemical fire-engine. The essential parts of this engine are a large closed tank, charged with a solution of bicarbonate of soda, and, inside the tank, a leaden jar containing sulphuric acid. At the proper moment, the acid is tipped into the soda solution, and the carbon dioxide which is generated exerts a pressure sufficient to force water a considerable distance or height. The advantage of this fire-engine is obviously that the chemical forces may be brought into play instantaneously; there is no necessity to wait until the steam is up.

The action between an acid and a carbonate may be used in another way in the direct extinction of small fires. It is well known that combustion is not possible in an atmosphere of carbon dioxide, hence if we can surround a piece of burning wood, for example, with such an atmosphere, we may smother the fire. This is the object of the fire grenades which are to be seen hanging in factories and public buildings. They contain the substances necessary for the production of carbon dioxide, and these

are brought together by throwing down and breaking the glass vessel in which they are contained.

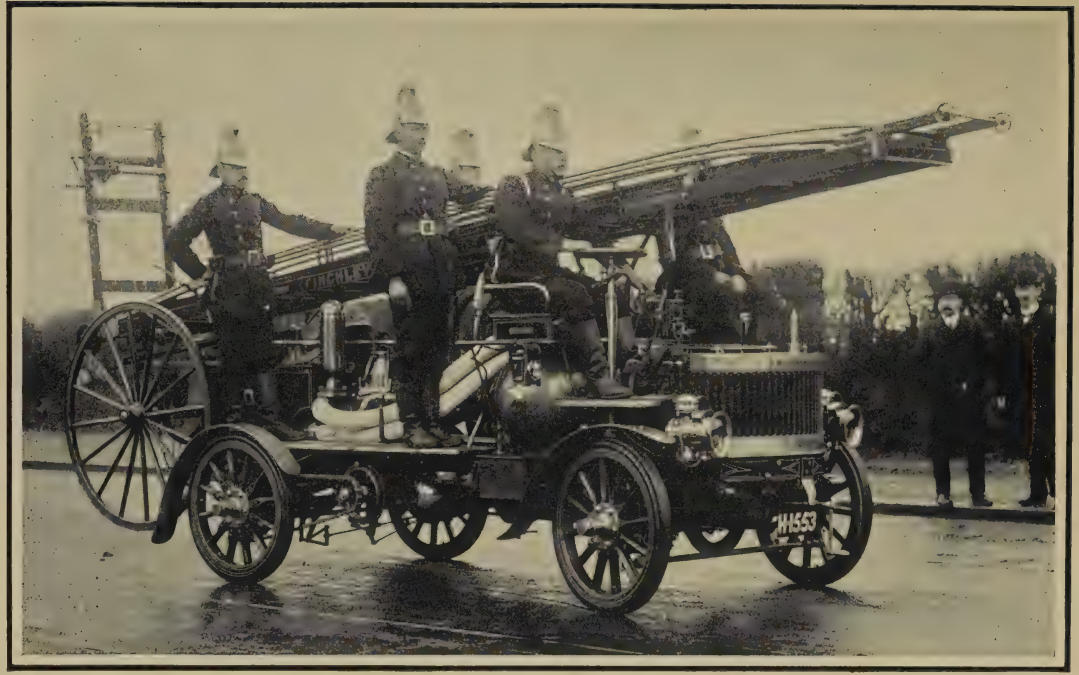
The reader is doubtless aware that much of our building material consists of limestone, the chief constituent of which is carbonate of lime. Bath stone and dolomite, for example, are affected by acids in exactly the same way as ordinary carbonates, and inasmuch as the air in our large towns contains some acid constituents, derived mostly from the sulphur in coal, calcareous or chalky stones like these are liable to disintegration. The Houses of Parliament and York Minster furnish examples of the way in which a calcareous building stone decays under the influence, amongst other factors, of the acid constituents of the atmosphere.

Bearing in mind another general characteristic of acids, we have a very simple clue to a conjuring trick which seems marvellous to the uninitiated. It is found that certain vegetable products assume one definite colour in the presence of acids, and another colour in the presence of alkalis, which, as we shall see presently, are the exact opposites of acids in many respects. A solution of litmus, for example, is turned red by acids, and blue by alkalis, while a solution of phenol phthalein is colourless in the presence of acids, and intensely red in the presence of alkalis. These substances are called indicators, and are of the greatest use in chemical work, because they enable the chemist so to neutralise any solution that it is neither acid nor alkaline. In the conjuring trick a series of glasses are rinsed out alternately with acid and alkali, and then water containing some phenol phthalein is poured from the first glass into the second, from the second into the third, and so on. What the spectator sees and marvels at is a

colourless liquid becoming suddenly red on being poured into an apparently empty glass, and the same red liquid becoming colourless again when poured into another also apparently empty glass.

As a class, alkalis are the opposite of acids, not only in regard to the indicators just mentioned, but in many other respects. The addition of an alkali to an acid destroys or neutralises the characteristic properties of the latter, and if the right quantity is added the solution then contains nothing but a salt—a kind of neutral substance which does not exhibit the behaviour either of an acid or of an alkali. The process of neutralisation may be represented in the following way: acid + alkali → a salt + water; from which it will be seen that the same sort of body is produced in this way as is formed by the action of an acid on a metal.

In certain circumstances an alkali may obviously be used as an antidote to an acid; if, for instance, a drop of an acid is allowed to fall on clothing, the production of a stain, and ultimately a hole, may be prevented by the immediate application of an alkali, for the salt which is thus formed is quite harmless so far as any action on the cloth is concerned, and may be washed out with water. Again, if any acid has been swallowed, an alkaline substance is the thing to take. In both cases, however, the right alkaline substance must be chosen, otherwise the cure may be worse than the disease; for certain alkalis have a very powerful action on animal and vegetable tissues, destroying such things as skin and paper. Two alkalis of this description are caustic soda and caustic potash, which, although extensively used in the manufacture of hard and soft soap respectively, are perhaps not so familiar to most people as



by permission of *Merryweather & Sons, Ltd.*

A Chemical Fire-engine

In such an engine the pressure required to throw water on a burning building is obtained by mixing a carbonate and an acid, and so generating carbon dioxide. A tank for holding the carbonate solution is seen in the illustration, underneath the driver's seat. The usefulness of such an engine is restricted to the early stages of an outbreak.

the so-called "mild" alkalis, carbonate of soda and carbonate of potash.

What has been said about an alkali acting as an antidote to an acid will enable the reader to understand that air containing carbon dioxide may be purified by passing over caustic soda. For carbon dioxide is an acid gas, and as such is readily absorbed by an alkali. Hence it is possible to devise an arrangement whereby a person may breathe in a closed space without suffering from accumulated carbon dioxide. It is only necessary that oxygen should be supplied to replace what is absorbed in the lungs, and that the exhaled air should be freed from carbon dioxide by contact with alkali before it is again inhaled. Both these conditions are fulfilled in the so-called oxygen respirating apparatus. This consists of a bag of air carried on the breast and connected by various tubes with (1) the mouth and nostrils, (2) a compartment filled with alkali, and (3) cylinders containing compressed oxygen and carried on the back. Any one provided with a portable apparatus of this description is independent of the surrounding atmosphere, and may therefore venture into places, entrance into which would ordinarily mean certain death. An equipment of this kind was used with success in the rescue work at Courrières, where, as the reader may remember, a very serious mine disaster occurred not very long ago.

But we must return to the question of the well-known alkalis. Solutions of these substances are soapy to the touch, and are extremely useful for cleaning purposes. One thing, however, which should not be cleaned with alkali is the modern aluminium ware used for cooking. Of the few metals which are dissolved by alkalis, aluminium is one.

Potash furnishes an interesting illustration of a useful substance coming from unlikely sources, of which two may be mentioned. Wood contains a certain proportion of potash, absorbed from the soil by way of food, and in countries which are well timbered potash is extracted from wood ashes, in which there may be as much as 10 per cent. of the alkali. Its very name is derived from the fact that the wood *ashes* are dissolved in water and the solution is evaporated down in iron *pots*.

Another and still more strange source from which potash is derived is the fatty matter in the fleece of sheep. This "suint," as it is called, contains quite an appreciable amount of the potassium salt of an organic acid, and when this is extracted, evaporated, and strongly heated, potash is left behind.

Besides the mild and caustic alkalis which have just been described, there is what is known as the "volatile alkali"—ammonia. Although this substance is a gas composed of nitrogen and hydrogen, it is an alkali just as much as caustic potash or washing-soda. It neutralises acids and exerts the same effects as other alkalis on litmus or phenol phthalein.

One of the most remarkable properties of ammonia gas is its extreme solubility in water. If a flask quite full of the gas is uncorked with the mouth under water, the latter will rush in and occupy the whole of the flask just as if there had been nothing there at all. Measurements have been made of the solubility, and it has been found that one cubic inch of water will absorb at the ordinary temperature as much as 700 cubic inches of ammonia gas. The solution so obtained may therefore be regarded as a convenient and compact form of ammonia, and it is this which is supplied to us when we ask for ammonia at

the shops. The liquid we buy contains a large proportion of water, but it would clearly be impracticable to buy and sell ammonia in the pure gaseous state.

This convenient way of handling a substance in solution instead of in the pure, undiluted state is employed also in the case of some of the acids. Oil of vitriol, to be sure, is almost pure sulphuric acid, but "aqua fortis" is only a solution of nitric acid, and "spirits of salt," as a rule, does not contain more than one-third of its weight of hydrogen chloride, which is itself a gas.

Ammonia, as an alkali, has the power of neutralising acids, and an interesting experiment which shows that the process of neutralisation leads to the formation of an entirely new substance, a salt, is the following:—A glass cylinder is filled with ammonia gas, and closed with a glass plate; a similar cylinder is filled with hydrogen chloride, and the two are placed mouth to mouth with the glass plate between. If the glass plate is slipped out, the colourless alkaline gas in the one cylinder and the colourless acid gas in the other immediately rush upon each other, and a white, powdery substance, sal ammoniac, is produced. Here we have the interesting case of two gases uniting to form a solid, entirely different in character from the original reacting substances.

Lime is another alkaline body, of which enormous quantities are required in the arts and manufactures, and yet the majority of people know very little about its valuable properties. Lime is the oxide of the metal calcium, and is obtained by strongly heating carbonate of lime, which nature supplies in profuse measure and in such various forms as marble, limestone, and chalk. We may note that from the point of view of ultimate chemical

composition chalk is as good as marble; it is only the poor brother in the family.

By dropping a little acid on marble, limestone, or chalk, we can satisfy ourselves that they give an effervescence of carbon dioxide. As a matter of fact, carbonate of lime is just a neutral salt formed by the union of the alkaline lime and the acidic carbon dioxide. This salt, however, differs from other common salts, because when it is heated it gives off its acidic component, the carbon dioxide, while the lime remains behind. This chemical change is carried out on the large scale when limestone is strongly heated in lime-kilns; the process is termed "lime-burning." The reader must not suppose that lime burns in the sense that a piece of coal does; the term refers only to the strong heating to which the limestone is subjected. The product of lime-burning is called "quick" lime, but for a great many purposes, such as the preparation of building mortar, this must be converted into "slaked" lime by the action of water.

The slaking of lime is a beautiful example of the changes brought about by a simple chemical action; for if a little water is sprinkled on one of the hard lumps of quicklime obtained from a lime-kiln, some remarkable effects are observed. For a minute or two nothing is apparent, but presently steam rises from the lime, and if the observer touches the mass with his hand he will realise that much heat is being generated. The chemical forces at work are such that the hard lump of lime splits up and crumbles down to a soft powder, which is absolutely dry in spite of the added water. The secret of this striking phenomenon is that a new chemical compound has been formed; the water

has united with the quicklime to produce slaked lime: hence its disappearance.

The slaking of lime is accompanied by a considerable increase in bulk, and this fact has been occasionally applied in the blasting of coal in fiery mines, where the use of ordinary explosives is dangerous. A so-called "cartridge" of quicklime is pressed into a cavity drilled in the coal, and water is then forced in by a pump. The result is that the lime slakes, and the force of the expansion which accompanies the slaking process is such as to plit the surrounding masses of coal—an excellent example this of the chemical energy latent even in the most commonplace materials. We do not usually associate anything very striking with such matter-of-fact substances as lime and water, and yet in their own quiet way they can together do the work for which the aid of a high explosive is generally requisitioned.

Lime is very extensively employed in the preparation of building mortar. For this purpose sand and slaked lime are used, and they are made up together with water until the mixture has a pasty consistency. The setting of mortar which occurs a few days after it has been made and applied is simply a process of drying by exposure to the atmosphere. But even after the mortar has set it undergoes a further change—it gradually hardens. This process of hardening is a chemical one, and is due to the slow absorption of carbon dioxide from the atmosphere.

It can easily be shown that lime has the power of absorbing carbon dioxide, for if lime water, which is simply a clear solution of slaked lime, is exposed to the air for some time, a white film of chalk collects on

the surface. So also the lime in mortar gradually absorbs carbon dioxide, becoming converted into the hard carbonate of lime. It will, of course, take a very long time for the hardening to be complete, but the examination of ancient mortar from Greek and Roman ruins has shown that in these cases the carbon dioxide absorbed from the atmosphere has been sufficient to convert all slaked lime into the carbonate. In fact, by pouring a little acid on a piece of old mortar any one can see that it contains a carbonate. Every stone or brick wall, therefore, in which mortar has been used must be pictured as the scene of a slow, imperceptible chemical change—a change which will probably go on as long as the wall lasts.

CHAPTER IX

NATURAL WATERS, AND WHAT THEY MAY CONTAIN

IT was a commonly-accepted idea among the ancients that fire, air, earth, and water were the four elements, the simplest forms which matter could assume. This conclusion was not reached as the result of experiments, of unsuccessful attempts to get at something more simple; for the ancient philosophers never made any chemical experiments at all. So far as they concerned themselves with the science, they were what we might call "study-table chemists," and they thought it a much finer thing to make theories than to make experiments. To indulge in the latter practice was regarded as an occupation quite below the level of a philosopher. Now all this has changed, and in the last two centuries men have used the experimental method with infinite skill and patience to wring from Nature many of her most valuable secrets. Amongst other things, it has been discovered that water is not an element, as the ancients thought, but is capable of being broken down into yet simpler and more elementary substances, hydrogen and oxygen. So far, then, the ancients were wrong, but at the same time they were correct in regarding water as one of the first-rank substances in Nature, not only because it is so

abundant, but because it is so absolutely essential to life of all kinds.

From the chemist's point of view, water is an exceptionally interesting substance. For, in the first place, it furnishes an excellent example of the thorough-going alteration which matter may undergo when it takes part in chemical processes. Think of it. Hydrogen and oxygen, the elements which combine chemically to form water, are gaseous, invisible substances which we may mix without any obvious change taking place. In the mixture neither gas interferes with the other, and each retains its own characteristics and properties. But bring a lighted taper or match near the mouth of the vessel which contains the gases, and what is the result? The gases, which have up to this point been in peaceful contact, are stimulated to mortal combat, a loud explosion occurs, and the gases are destroyed, leaving behind only the sweat of battle in the shape of a few drops of water. One has seen a conjurer converting handkerchiefs into rabbits, and a pack of cards into thin air, but his feats are tricks after all, and the more genuine cause of wonder is to be found in the marvellous things which Nature has to show. Among these marvels are such changes as that by which hydrogen and oxygen are converted into water, a substance with absolutely new properties and characteristics.

Water, however, is interesting in other ways. Has the reader ever observed that ice floats in water? He may have seen it, but not perceived it. Probably the fact has just been accepted as a matter of course, without any inkling of its importance. But the truth is that water is somewhat eccentric in this respect. Generally speaking, when any substance is exposed to lower and

Photo Frith

A Wonderful Result of Prolonged Chemical Action

This striking array of stalactites and stalagmites is found in one of the caves at Cheddar, in Somerset. These icicle or pillar growths consist of chalk (carbonate of lime) extracted by percolating water from the limestone rocks above the cave.

lower temperatures, and thereby passes from the condition of a gas to that of a liquid, and from the condition of a liquid to that of a solid, it shrinks and becomes more dense—that is, a given bulk of the substance weighs more and more. Water, however, is peculiar. As the temperature falls, it changes from steam to liquid water, and from liquid water to ice, but there is not throughout these changes a continuous increase of density. Water does indeed become more and more dense down to a certain point, 39° Fahrenheit, but here it reverses its behaviour; it expands and becomes lighter as it gets colder. So it comes about that ice is lighter than the water from which it freezes, and accordingly floats on the surface of the water. A little thought will show how significant this fact is in the economy of Nature, for the preservation of life in our lakes and seas during a severe winter is possible only because the surface ice protects the water underneath from freezing.

The same fact, however beneficial in its consequences in the realm of Nature, is liable to put us moderns sometimes to considerable inconvenience. We fit our houses with water-pipes, and it is only when the grip of winter has been unusually severe and our pipes are burst, that we learn that Nature will have her way in spite of our devices. Since ice occupies more space than the same weight of water, the pipes are burst when the water freezes, although it is not till the thaw comes that the damage is revealed to us.

Now the waters with which Nature supplies us, not always very regularly, according to our way of thinking, are never pure from the chemist's point of view. Many of them are fresh and quite suitable for drinking purposes, but even they contain substances which make them a little

different from pure water. Thus it is well known that practically all natural waters contain in solution an appreciable amount of solid matter. A large part of this solid matter may be deposited when the water is boiled, and a glance inside the kitchen kettle will, in many cases at least, suffice to show that this is the case. The so-called "furring" of a kettle is simply due to the solid matter depositing when the water boils. The same thing happens in engine boilers, and the incrustation or scale that forms on the plates of the boiler is a cause of serious trouble. For it is very difficult to remove the scale without damaging the boiler, and so long as it is allowed to remain extra heat must be supplied to the boiler if the output of steam is to be maintained. The extra heat is required because the scale is a bad conductor of heat; it has been found that a boiler incrustation one quarter of an inch in thickness involves a consumption of fuel 50 per cent. greater than would be required if the boiler plates were clean.

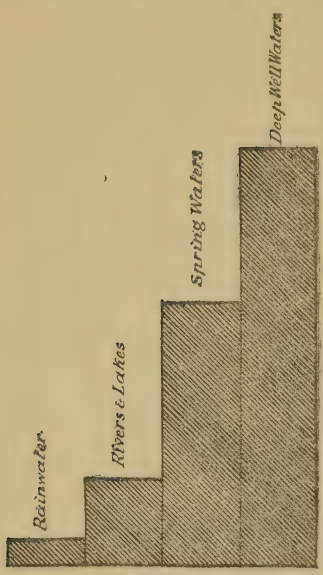


FIG. 2.—Showing the relative amounts of solid matter dissolved in various waters.

Different natural waters contain quite different amounts of dissolved solid matter. Some, such as sea water, contain a great deal; others, such as rain water, contain very little. A good idea of the relative average amounts

of solid matter contained in fresh waters from various sources will be obtained by a glance at the accompanying diagram. The heights of the columns are proportional to the amounts of solid matter in the various waters. Deep-well waters contain on the average about half an ounce of solid matter for every thousand ounces of water, and the proportion of solid matter in the other fresh waters may be roughly gauged from the diagram. If the amount of solid in sea water were to be represented in the same way, a column eighty times as high as the highest in the diagram would have to be introduced. This obviously must be left to the imagination of the reader.

To the ordinary individual, waters are familiar as "hard" or "soft," and this classification gives a rough idea of the amount of solid dissolved in the water. Hard waters contain a large amount of solid; soft waters, which require but little soap to make a lather, are those which are comparatively free from dissolved solid.

The question next arises, what are the solids that we find in the various natural waters, and where do they come from? If sea water is left out of account for the present, it may be said that the main substances occurring in natural waters are sulphate and carbonate of lime (and magnesia, to a less extent). The proportion of these substances held in solution by a water depends on its history.

As a matter of fact, carbonate of lime (chalk) is not soluble in pure water, but only in water charged with carbon dioxide. If now the reader recollects that there is opportunity for rain to become charged with carbon dioxide from the atmosphere, he will understand that the water which falls on the surface of the earth and percolates through the soil and the rocks will have the power of

LIBRARY
PROVO, UTAH

dissolving from these the carbonate of lime which they contain, as well as more soluble substances. When this water comes to the surface again in a well or spring it is found to be hard. But the simple process of boiling may render it comparatively soft, since in this operation the carbon dioxide with which the water is charged is boiled out, and the carbonate of lime, being no longer soluble, is deposited. That the "furring" in the aforementioned kitchen kettle is caused by a carbonate is shown by the effervescence which occurs on the addition of a little hydrochloric acid—"spirits of salt," as it is commonly called.

Apart from actual boiling, mere exposure of such a hard water to the air will deprive it of its carbon dioxide by evaporation, and in so far as the carbon dioxide is removed, in so far is a deposit of carbonate of lime produced. This is the way in which these curious excrescences known as stalactites and stalagmites are formed. Water which has percolated through some depth of soil and rock, and become hard in the process, may arrive at the roof of some underground cavern. The drops which there form are subject to evaporation, and part of the carbon dioxide with which they are charged is removed. This leads to the deposition of chalk, and a tiny contribution is made to the growth of the stalactite. A further quantity of carbon dioxide evaporates as the drops fall on the floor of the cavern, a further deposit of chalk is formed, and a tiny contribution is made to the growth of the stalagmite column.

Another very interesting natural phenomenon closely related to the formation of stalactites and stalagmites is the action of what are known as "petrifying springs." If a wicker basket, for example, is exposed to the action

VIAGGI
NATURA

of such a spring, it is gradually impregnated and coated with a stony-like substance. The explanation is that the water of a petrifying spring is hard, and contains a considerable quantity of carbonate of lime in solution. When the water comes to the surface it deposits carbonate of lime, because it loses by evaporation some of the carbon dioxide in virtue of which it has the power of dissolving that substance. This deposition of calcareous matter may take place on any objects, such as leaves or twigs, exposed to the play of the water, but it is thought by some people that certain bog-mosses or water-plants are specially effective in causing decomposition of the carbonic acid, and thereby inducing the deposition of a crust of carbonate of lime on their stems and branches.

Most of the water which has percolated through the soil and the rocks, and thereby collected a certain amount of solid matter, finds its way into streams and rivers and ultimately into lakes and seas. It will be obvious that the amount of solid matter in the sea and in lakes which have no outlet must be gradually increasing, since the supply of water is roughly balanced by continual evaporation from the surface. The rate of increase of the solids in sea water is very small because of the enormous quantity of water, but in the case of an inland lake in a hot climate, where there are heavy rains alternating with periods of rapid evaporation, the amount of dissolved solid is very high and increases fairly rapidly.

The Dead Sea is a case in point. Its waters are exceedingly brackish, and contain no less than about a quarter of their weight of solid matter, mostly sodium chloride (common salt) washed out from the neighbouring hills. The presence of so much solid makes the

water of the Dead Sea considerably heavier, bulk for bulk, than fresh water; it is so dense that eggs will float in it, and it will not allow the human body to sink. Ordinary sea water also is somewhat denser than fresh water, and its superior buoyancy is possibly known already to the reader by personal experience.

Much of the water which is distributed over the surface of the globe is quite unsuitable for the use of man. All brackish waters come under this category; and many an unfortunate sailor who has been cast adrift at sea has realised the bitter truth that there was "water everywhere, but not a drop to drink." Even from sea water, however, it is possible to obtain pure water by the process of distillation. The water is boiled in a suitable vessel, and the steam is led away through a cooled pipe, at the end of which the condensed water may be collected in a pure state. The solids dissolved in the sea water are not volatile, and are accordingly left behind in the boiler. At the present day much of the fresh water required on board our great ocean liners is obtained by subjecting sea water to distillation.

When one thinks of it, Nature herself is constantly making use of this process. The evaporation that continually takes place from the surface of the ocean is really a slow distillation; the water vapour condenses into clouds, and falls, some of it at least, as rain on the surface of the land. Rain is natural distilled water.

For many domestic and industrial purposes it is necessary to purify even ordinary fresh water, especially when it is hard. This process of "softening" water may be effected in several ways. It has already been stated that mere boiling will diminish the hardness of a water, but even water that has been boiled will not

at once give a lather with soap. Instead of giving an immediate lather, a curd is formed—evidence that the sulphate of lime still remaining in the water is being removed or precipitated by the soap. Only after this removal is complete will the soap form a lather.

The lime in a hard water may be removed also by the addition of sodium carbonate—washing-soda, as it is commonly called—or of lime water. If the water is to be obtained free from the deposit of chalk which both these substances produce, it must be allowed to stand in tanks, and then run off after the precipitate has settled to the bottom.

Occasionally the impurities in a water are of an organic nature, and these may be such as to render the water unsafe for drinking purposes. This organic matter may come from decomposing vegetable substances, or it may be of animal origin, and come from sewage or surface drainage. Sometimes our senses of taste and smell will warn us of this, but in the last resort we must depend on a chemical and bacteriological examination of the water. Such an examination will reveal, in the case of a polluted water, an unduly high amount of nitrogenous compounds, and possibly also large numbers of disease germs. To make the water safe, it must either be filtered through sand or unglazed porcelain, or it must be sterilised by boiling. All germs seem to find exposure to boiling water a somewhat trying experience, and few survive the ordeal. This will be clear from a special example which has been put on record.

A particular water of bad quality was found to contain 460,000 germs per cubic centimetre. Exposure to a temperature of 194° Fahrenheit for ten minutes reduced the number to twenty-six, and even these hardy individuals

had to give up when the water was boiled for ten minutes. As the palatable quality of a water depends on the quantity of dissolved gases, such as oxygen and carbon dioxide, the device of boiling it renders it somewhat insipid. If this is considered a disadvantage, it can be made more palatable by aeration, that is, by shaking it for a little with air.

Besides the various kinds of fresh water and the brackish water of our seas and inland lakes, Nature supplies us here and there with waters of a peculiar kind, distinguished not so much by the quantity of matter which they contain as by the fact that this matter is of an unusual kind. There are the so-called "mineral waters," which, in many cases at least, come from considerable depths below the surface, and are frequently hot on that account. Some of the well-known mineral waters are alkaline and contain carbonate of soda, notably those which are charged with extra large quantities of carbon dioxide, such as Apollinaris and Seltzer waters. Carbon dioxide has been forced into these waters under high pressure far below ground, and when they come to the surface and under the lower pressure which prevails there they cannot contain themselves, as it were, and so are marked by their characteristic effervescence.

Here and there one finds iron or chalybeate springs. Carbonate of iron, like carbonate of lime, is not soluble in pure water, but is taken up by water charged with carbon dioxide. Thus it is possible to obtain a water which holds in solution a considerable quantity of otherwise insoluble iron. When such a water comes to the surface, it loses some of the carbon dioxide with which it is charged, and the channel down which the water runs

Photo *Copyright, 1882, by C. H. James*

A Wonderful Ceiling

An underground cavern (Luray in the United States), called the Ballroom, the roof of which has been fashioned by the continual drip of water charged with carbon dioxide and carrying chalk in solution.

away is tinged a yellowish or reddish colour, owing to the action of the oxygen in the air on the carbonate of iron deposited from the spring water.

Saline springs containing sulphate of magnesia and sulphate of soda are frequently found. The waters of these springs are bitter and act as purgatives. It is interesting to note that sulphate of magnesia is commonly known as Epsom salts, on account of the fact that it was found in a spring at Epsom by a London physician of the seventeenth century. There are springs of this class in other parts of England, but the best known spas at which bitter waters are available are Sedlitz, Friedrichshall, and Kissingen.

Other mineral waters which are peculiar are those which contain sulphur in some form or other; the springs at Harrogate and Strathpeffer are the best known of the kind in this country. Owing to the sulphuretted hydrogen and the sulphide of soda which these waters contain, they have an unpleasant taste and smell, but they are much valued for their medicinal properties. Those happy individuals, however, who have hitherto escaped the ills to which flesh is heir, will have no desire to cultivate a closer acquaintance with sulphur springs.

CHAPTER X

CHEMICAL CHANGES WHICH PRODUCE LIGHT AND HEAT

TO the popular mind a chemical laboratory is suggestive of explosions—reactions which result in the very evident production of light and heat, and sound into the bargain. But it is not necessary to visit a chemical laboratory in order to observe chemical changes which produce light and heat, for we are all chemists to some extent, at our own firesides. When we strike a match or light a fire we make a chemical experiment, but the "Red Flower" is so familiar to us that we miss the meaning and the marvel of it.

The making of fire is one of the oldest chemical achievements of the human race, and in our modern world the part played by combustion is of enormous importance. A little thought will show it is on those chemical changes which produce light and heat that we depend for a great many of our modern social conveniences. Where does the power come from which drives our motor cars? Why, from the combustion of petrol. Further, when a man stands on the footplate of a "Flying Scotchman," or in the engine-room of the *Mauretania*, he begins to understand what wonders in the way of locomotion we owe to the combustion of coal.

"Ah, yes!" some reader may say; "but we are going in for electricity nowadays, are we not? We are lighting

our streets with electric light instead of gas, and our railways are being electrified." That is all quite true, but even then we have not got rid of combustion as the source of nearly all our energy. Except where water-power is available, the introduction of electricity means simply that the combustion has been centralised. Instead of burning gas at each street lamp, we burn coal or gas at some central furnace, and use up the energy of combustion in driving a dynamo; instead of having a fire on each locomotive we have again a central furnace at the power-station. Hence the production of energy, whatever its form, still depends almost exclusively on the time-honoured process of combustion.

Now, although the various things which are burned for the purpose of producing light and heat are outwardly very different—gas, coal, paraffin oil, candles, wood, methylated spirits, petroleum, peat, &c.—the process of combustion is essentially the same in each case. The substances just mentioned are alike in containing carbon and hydrogen, either in the form of the elements themselves, or in the form of compounds, and the process of combustion is simply the chemical combination of these two elements with the oxygen of the atmosphere. Hence, if we understand what happens in the combustion of a candle, for example, we should be able to give an intelligent explanation of what takes place in a paraffin oil lamp or in a coal fire.

When the carbon and hydrogen in a candle combine with the oxygen of the atmosphere, the products are our old friends carbon dioxide and water. Carbon dioxide is an invisible gas, as the reader will remember, and the water formed in the flame is given off as an invisible vapour. The candle, therefore, gradually disappears as

it burns, leaving little or no trace behind. To the superficial observer the fact that the candle disappears and leaves nothing tangible in exchange might seem to throw doubt on the law of conservation of matter, according to which matter cannot be destroyed. But it will be admitted that the law would still be fulfilled if the disappearance of so much matter in one form were compensated by the production of an equivalent amount in another form ; and the reader who has followed the argument of the foregoing chapters will recognise that some forms of matter are invisible.

The fact is, the invisible products of the combustion of a candle—that is, the carbon dioxide and the water vapour —weigh more than the candle. This is only natural, for just as it takes two to make a quarrel, so there are two parties to a combustion, namely, the combustible substance, in this case the candle, and the supporter of combustion, the oxygen from the air. As the combustion consists in a *combination* of the carbon and hydrogen of the candle with the oxygen of the air, the products are necessarily heavier than either the candle or the oxygen separately. The chemist can easily show that this is so by absorbing and weighing the carbon dioxide and water, but it will be sufficient for our purpose to show that each of these substances is present in the gases arising from a candle flame.

In order to show that carbon dioxide is one product of a candle flame, we may fix a small piece of candle on a wire, light the candle, and lower it into a glass jar, into which we have previously poured a little lime water. When the candle has been allowed to burn in the jar for ten or fifteen seconds, it is taken out, the jar is closed by a cork, and the contents are shaken. It will then be

seen that the lime water has become turbid, showing that the air left in the jar after the burning of the candle contained carbon dioxide.

The production of water in the flame of a burning candle may be very readily demonstrated with domestic apparatus. A tumbler of cold water, the colder the better, is carefully wiped on the outside, so that it is perfectly dry, and is then held a little above the candle flame. The outside of the tumbler at once becomes cloudy owing to the condensation of tiny drops of water.

The extent to which carbonaceous fuel is converted into carbon dioxide and water depends on the supply of the air which supports the combustion. If for any reason the supply of air is cut off, combustion ceases. Hence it comes that a candle cannot continue to burn in a closed space for more than a very short time. Not only does it exhaust the oxygen, but by its own combustion it produces substances which are unfavourable to a continuance of the process. In an atmosphere of carbon dioxide and water vapour no combustion is possible. On the other hand, the more air or oxygen we supply to the burning fuel, the more complete is the combustion.

The oldest method of supplying more air to burning fuel, and thereby securing more complete combustion, is the familiar one of making a draught. The difference between an oil-lamp flame with the chimney off, and the same flame with the chimney on, is due to the draught which the chimney makes ; this draught means an inrush of air at the bottom of the chimney and a better supply of oxygen to the flame of the burning oil.

Perhaps the reader has tried sometimes to fan the flickering flame of a newly-lit fire by holding a newspaper in front of the upper part of the grate. The result of

this is that the chimney draught sucks the air right through the fuel, which is thereby fed more perfectly with the oxygen it so badly needs. If the newspaper were not there, the bulk of the air which is drawn up the chimney would come in through the upper part of the grate front, without passing through the fuel. The village blacksmith, too, when he makes his bellows roar, is in quest of more rapid combustion, and consequently more intense heat.

Imperfect combustion is responsible for the smoke that hangs like a pall over so many of our large cities. We in England insist on having the cheery but unscientific open fireplace, with the result that the fuel is imperfectly burned, and our chimneys pour a constant stream of smoke into the atmosphere. Smoke is charged not only with finely-divided carbon and soot, but also with oily and tarry vapour, whereas if there were perfect combustion nothing but invisible gases would leave the chimney. Just imagine what that would mean! Apart from the saving in fuel, we should never require the services of the chimney sweep, and we should be spared many of the grimy fogs which come, especially in London, to clog our breathing organs and to depress our spirits.

Why should it be so uneconomical and unscientific to burn coal in such open fireplaces as are common in England? The key to the answer lies in the fact that when coal is heated it first gives off a quantity of inflammable gas, and it is really this gas which burns when we put coal on a fire. But unfortunately in our open fires the fresh coal is put *on the top*, so that the gas which comes out of the coal as it gets warmed up is in a part of the fire where the supply of oxygen is limited. Not only has a considerable portion of the oxygen been used

A Big Blaze at Baku

At Baku in the south of Russia there are enormous natural stores of petroleum, and when they are tapped the petroleum gushes up with extraordinary force. Occasionally one of these oil fountains catches fire and the result, as shown in the illustration, is a column of fire 200–300 feet high, surmounted by a huge cloud of smoke.

up in the combustion of the glowing fuel at the bottom of the grate, but the carbon dioxide which is produced there, and which ascends through the freshly-added fuel, makes it impossible to get perfect combustion of the latter. Hence it comes that quite a respectable fraction of our best household coal simply goes up the chimney unburnt, to become subsequently a nuisance to ourselves and our neighbours.

The abolition of smoke is a consummation devoutly to be hoped for, and considerable advance has already been made in that direction. Improvement has been effected chiefly in the diminution of smoke emitted from factory chimneys. For this we are indebted, partly at least, to the introduction of mechanical stokers, which feed coal into factory furnaces so that the fresh fuel is put where it has an excellent supply of oxygen. The mechanical stoker subsequently moves the coal on to other and hotter parts of the furnace, and it has the further advantage that it obviates the necessity of opening the furnace doors—an operation which involves the admission of a draught of cold air.

Appliances have been devised for securing more perfect combustion in house fires by introducing the coal from below, but none of these have come into general use. The adoption of such a plan would involve the reconstruction of all our fireplaces.

Another method of getting rid of the smoke nuisance is to subject the coal to destructive heating in a gas-works, and to use the gas so obtained for heating purposes instead of coal. This is the plan that will probably be adopted in the long run. A gas stove is, however, much less fascinating than a coal fire ; sentiment clings round the old fireside, and the institution will die hard.

When gas (or a candle) burns in the air, the supply of oxygen is not sufficient for complete combustion of the carbon and the hydrogen, except in the outermost envelope of the flame, and the fact that we get any light at all from an ordinary gas or candle flame is due to a host of unburnt particles of carbon in the interior. These particles are raised to a white heat by the flame, and so make it luminous. That the ordinary gas or candle flame contains particles of carbon may be very easily shown by holding a cold surface just into the top of the flame, when a deposit of soot (that is, carbon in a finely divided form) is obtained.

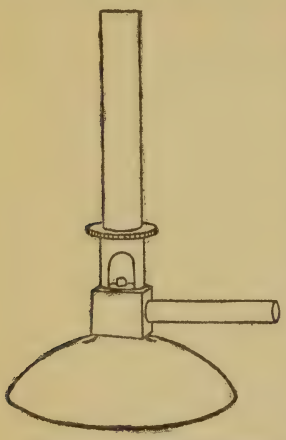


FIG. 3.—A Bunsen Burner.

When the supply of air to a gas flame is increased by mixing the gas with air just before it reaches the actual place where it is burned, then the combustion is more complete, the flame is hotter and no longer luminous. The particles of carbon which ordinarily make the flame luminous are now all converted into carbon dioxide, even in the interior of the flame, by the extra oxygen supplied. This is the principle of the well-known Bunsen burner, which finds application now, not only in the laboratory but in our houses, on incandescent burners and gas stoves.

A simple Bunsen burner is shown in the accompanying diagram. The current of gas which rushes out at the central nozzle sucks in air through the surrounding holes at the bottom of the burner, while the mixture of air and gas ascends, and is burned at the top of the tube.

The flame is very hot, gives out almost no light, and if a cold surface is put into the flame, no soot is deposited. This kind of flame is therefore especially suitable for heating and cooking purposes, for blackening of the utensils is avoided. The part played by the air in such a burner can be very simply demonstrated. If the burner is lighted and the observer puts his fingers over the air inlet holes at the bottom of the tube, the flame, instead of giving practically no light, becomes luminous at once.

If the reader will take the trouble, this little experiment may be carried out with an ordinary incandescent burner. The air inlet holes are easily discovered, and if the burner is lit on some occasion when the mantle has been removed, the effect of letting in or shutting off the extra supply of air is very evident.

It has been already stated that an ordinary gas or candle flame is luminous because it contains particles of unburnt carbon which are raised to incandescence, and so emit light. If this is so, then we may expect that if we take a non-luminous flame like that of a Bunsen burner, and introduce into it some solid substance which can stand a very high temperature without melting, this flame will become a source of light. This is exactly the principle which has been applied in our modern incandescent burners. As has just been pointed out, the flame of an incandescent burner, apart from the mantle, is quite without luminosity, and the mantle is simply an infusible substance which is raised to incandescence by the heat of the flame.

A similar device used to be much in vogue for the exhibition of lantern slides—in the so-called lime-light. By allowing a very hot flame to play on a little lump of

lime, the latter is raised to a white heat, and emits a very powerful light.

In an electric glow lamp the light proceeds from a carbon filament raised to incandescence, but in this case the source of heat is an electric current, not a flame of burning gas. The electric glow lamp furnishes at the same time an interesting illustration of what has been said about there being two parties to a combustion. The filament in the lamp is made of carbon; there it is, glowing brightly, and yet apparently it suffers no wastage; it appears to burn, but it is not consumed. Why is this? Because the other party to a combustion, the oxygen, is absent on this occasion. The lamp has been rendered vacuous during the process of manufacture—that is, the air which it contained was removed—and so no combustion is possible. The tender little filament is protected by its glass cage from the hordes of oxygen molecules that would be only too ready to fall upon it if they had the chance.

It must not be supposed that the term combustion is to be applied exclusively to those cases where a carbonaceous fuel is burned. Many other substances combine readily with the oxygen of the air, and the chemical change involved in this combination produces light and heat.

Everybody who has seen an underground cavern illuminated by the burning of magnesium ribbon knows what an intense light is emitted in this process; and the process is essentially the same as the burning of a piece of charcoal. When charcoal is burned, oxide of carbon (carbon dioxide) is produced; when magnesium is burned, oxide of magnesium (magnesia) is produced.

The burning of magnesium illustrates very excellently

one or two points which have been mentioned already. In the first place, it shows what fundamental changes those substances undergo which take part in a chemical action; we start with a piece of metallic ribbon and the invisible air, and there is left behind a soft, white, powdery mass of magnesia. In the second place, the intense light observed when magnesium burns is due to the presence of little particles of infusible magnesia, which are rendered incandescent by the great heat of the chemical action.

Again, it is easy to show that just as the carbon dioxide and water produced by the combustion of a candle are heavier than the candle, so the white powder produced by burning a piece of magnesium ribbon weighs more than the ribbon. The discovery that the products of combustion are heavier than the combustible substance was really a very important one in the history of chemistry; for up to about 120 years ago it was generally supposed that a combustible substance contained something called phlogiston, which came out of the substance when it was burned. It was the famous French chemist Lavoisier who finally overthrew this theory, and emphasised the fact that instead of losing anything when it was burned, a combustible substance actually became heavier.

The meaning of the term "combustion" has been extended in the foregoing paragraphs so that the burning of coal and the burning of magnesium are brought under the same category. We may now extend the term still further to cover many chemical processes, which, although they do not very obviously produce light and heat, yet depend essentially on the same chemical phenomenon, namely, the combination of some substance with the oxygen of the atmosphere. These are cases of slow com-

bustion, and may be referred to generally as oxidation processes.

One of these processes, which, without producing any light, produces a good deal of heat, is the respiration of animals. What goes on in our bodies, through the agency of the lungs and the blood, is neither more nor less than a combustion, in the course of which the carbon compounds in the body, the fat, &c., are burned to carbon dioxide and water.

It is very easy to show that air expired from the lungs is heavily charged with carbon dioxide. Ordinary fresh air contains so little of this gas that a pint bottle full produces no milkiness when shaken up with a little lime water. But if the air which we breathe or blow out from our lungs is made to bubble through a little lime water, a very marked turbidity appears. Exact measurements have shown that whereas fresh air contains 3 to 4 parts by volume of carbon dioxide in 10,000, the air which issues from the lungs is charged to the extent of 400 to 450 parts carbon dioxide in 10,000. A little carbon dioxide is also given off through the skin, and it is computed that the total carbon dioxide evolved by the lungs and skin is about three-quarters of a cubic foot per hour. An ordinary gas burner produces about one and a half cubic feet of carbon dioxide in the same time, so that as far as the contamination of the air in a room is concerned, a gas burner is equal to two men.

Another change which comes under the same category as respiration, and which we might describe as a slow combustion, is the rusting of iron. Rusting is the combination of the metal with the oxygen of the air, and is thus exactly parallel to the burning of magnesium ribbon, except that it takes so much longer. The total heat evolved

in the process of rusting is not any less than it would be if the oxidation took place rapidly; it is only spread over such a long time that the evolution of heat at any particular moment is not noticeable.

Rusting is an example of spontaneous oxidation. It is not necessary to strike a match to start the process; rusting is only too ready, as we often know to our cost, to start on its own account. It is, indeed, essential that carbon dioxide and moisture should be present before rusting can take place, but these substances are both present to some extent in ordinary air, and the only way to keep iron from rusting is either to paint it, or to plate it with some other metal which is less ready to hold traffic with the air. Metals which are commonly used for this purpose are zinc, tin, and nickel. Galvanised iron and tinplate, which are manufactured in such large quantities, are simply iron which has been coated with zinc and tin respectively in order to protect it from corrosion. Every cyclist knows that so long as the nickel-plating of his handle-bars is intact there is very little tendency to tarnish, but that wherever the protective layer of nickel has been removed rust is not long in putting in an appearance.

CHAPTER XI

HOW FIRE IS MADE

IN the forgoing chapter it has been said that the making of fire is one of the oldest achievements of the human race. So old is it that there is no trustworthy evidence of any tribe which was ignorant of fire and its uses. There is nothing impossible in the supposition that there may have been such a tribe, but we have no proof. It should be remembered that man must have been familiar with fire on the large scale, even before he knew how to produce it himself; for we may presume that lightning and volcanic eruptions have always been features of life on the earth. Apart, however, from these exceptional manifestations, the primeval man must one day have discovered how to produce fire with the ordinary means at his disposal. The reader can imagine the amazement and delight, perhaps the alarm, of the first human being who succeeded in making fire for himself, and of those who afterwards made an independent discovery of the same thing. How it was actually done we can only conjecture, but we shall probably get fairly near the true answer if we can discover the methods of making fire which have been practised among primitive tribes even in comparatively recent times.

The ancients solved the problem of the original discovery of fire in a manner that has the merit of simplicity, even if it does not commend itself to the scientific mind of this

twentieth century. They supposed that fire had been stolen from heaven by Prometheus, who carried it off in a hollow tube; while, according to another account, he obtained it by holding a rod close to the sun. "A fairy story," some reader will say; and certainly one feels that the ancients, having looked at the difficulty, simply told a pretty tale and passed by on the other side.

All the chemical methods of producing fire, those, namely, which are now employed, are comparatively new, and up till about a century ago, only what we might call mechanical methods were available. Friction, for example, as everybody knows, produces heat, and one of the oldest ways of producing fire consisted in rubbing one stick against another until the wood inflamed. In some primitive tribes a stick was pushed backwards and forwards in a groove in a piece of wood; sometimes the one stick was used as a drill, and was rapidly rotated in a hole cut out of a fixed block. Evidence of the extraordinary dexterity with which these fire-sticks can be manipulated by savages is found in Captain Cook's description of the production of fire among some Australian tribes. He writes: "To produce fire they take two pieces of dry, soft wood, one a stick about 8 to 9 inches long, the other flat; the stick they shape into an obtuse point at one end, and pressing it upon the other, turn it nimbly by holding it between both their hands, as we do a chocolate mill, often shifting their hands up and then moving them down upon it, to increase the pressure as much as possible. By this method they get fire in less than two minutes, and from the smallest spark they increase it with great speed and dexterity." How we should grumble nowadays if we had to work hard for two minutes before getting a light! The chances are that the savage would beat the civilised man

at this game, and we moderns would probably require much more than two minutes to produce fire with these primitive appliances.

Another elementary way of making fire is to strike flint and steel together, allowing the sparks which are thrown off to fall among some easily-ignited material such as tinder. This latter substance consists of the element carbon in a finely-divided condition, and is obtained by charring fragments of linen. The tinder, although it is not actually inflamed by a spark, glows with sufficient heat to ignite sulphur-tipped wooden splints—"spunks," as they used to be called.

The flint and steel method of obtaining fire for domestic and other purposes was known to the Greeks and Romans, and was the one commonly in use in most countries up to the end of the eighteenth century. Even the inhabitants of such an out-of-the-way place as Tierra del Fuego have for centuries been accustomed to get fire in this way, only instead of steel they used pyrites—a mineral compound of iron and sulphur. It appears, in fact, that this mineral got its name from the use which was originally made of it in this way. Both flint and pyrites received the name of "fire-stone" (Greek πυριτης).

Another curious device which may be employed in making fire depends on the fact that if air is suddenly compressed, heat is produced. A simple instrument based on this principle and known as a "fire-syringe" or a "pneumatic tinder-box" is to be found in any list of scientific apparatus. It consists of a glass tube fitted at both ends with brass caps, through one of which moves a rod with piston attached. If a piece of tinder is put in the bottom end of the tube, and the

air in the tube is compressed by rapidly pushing down the piston, the tinder ignites. A similar apparatus, with a tube, however, of hard wood or ivory, has actually been found in use in Burmah.

Among the mechanical methods of producing fire we must not forget to reckon the lens or burning-glass, by which the rays of the sun may be focussed at a point. Combustible material which will not ignite when merely exposed to the sun will at once take fire if brought to the point at which the heat is thus concentrated. The burning-lens was known to the Greeks, and is commonly used by the Chinese. Some readers may remember the story according to which Archimedes, during the siege of Syracuse, set the Roman fleet on fire with the aid of burning-glasses. It is rather a "tall" story, not confirmed by the historians, but it serves at least to show that the use of the lens in the production of fire was familiar to the ancient world.

All the foregoing methods of obtaining fire are physical or mechanical methods, and it was not till 1805 that an attempt was made to employ a chemical method for the purpose. In that year a certain Frenchman showed that splints of wood coated with sulphur and tipped with a mixture of chlorate of potash and sugar would ignite when brought into contact with sulphuric acid—oil of vitriol, as it is commonly called. The chemical action which takes place spontaneously between the acid, the chlorate of potash, and the sugar is accompanied by the evolution of so much heat that ignition takes place, the sulphur first and then the wood bursting into flame.

The first really practical lucifer matches were made in England about 1827. They consisted of wooden splints or sticks of cardboard coated with sulphur, and

tipped with a mixture of sulphide of antimony, chlorate of potash, and gum. They were ignited by being drawn between two folds of glass paper tightly pressed together, and a piece of this paper was supplied with each box. These matches required much pressure for ignition, and as they were liable to throw off sparks, they required careful handling. A shilling per box of eighty-four was the price, and it is instructive to compare this figure with the cost nowadays, when we can get as many as four hundred for a penny.

The great modern development of the match industry began with the introduction of phosphorus. This element was discovered and its properties were known long before, but its application in the manufacture of matches began in the thirties of last century.

Phosphorus in the ordinary condition is a wax-like substance which melts at 111° Fahrenheit, and takes fire very readily just above its melting-point. It is, in fact, this property of very ready ignition which makes phosphorus valuable in the manufacture of matches. The slightest friction will cause it to catch fire, and hence if a splint of wood tipped with some mixture containing phosphorus is rubbed against a rough surface—for example, sand-paper—it will ignite immediately. The ignition is much facilitated by mixing the phosphorus with an oxidising agent, that is, a substance which contributes to the combustion of the phosphorus by supplying it with oxygen. Saltpetre, chlorate of potash, and red lead, which all contain a high percentage of oxygen, are the substances chiefly used for this purpose. In addition to these two essential constituents of a match-tipping mixture, namely, the phosphorus and the oxidising agent, there are also binding ingredients, generally glue,

colouring matters, such as ultramarine or vermilion, and gritty material, such as powdered glass or fine sand, the object of which is to increase the susceptibility of the mixture to friction.

In order that the splint might be sure to catch when the match was struck, it was at one time customary to dip it in sulphur before tipping with the phosphorus mixture. The combustion of the latter lasts only a moment; the sulphur, on the other hand, burns slowly, and allows a little more time and opportunity for the wood to catch. Sulphur-coated splints are out of date now, and are met with only in cheap matches of continental manufacture. Instead of sulphur, paraffin is frequently used; it acts similarly as a go-between for the explosive mixture at the tip and the wooden splint.

The use of ordinary phosphorus in matches has many disadvantages. Their dangers have been impressed on many of us by "The Dreadful Story of Harriet and the Matches," and their use has most certainly led to numerous fires. In addition to this objection, there is the fact that phosphorus is poisonous. Workers in match factories, who are exposed to the vapour of phosphorus, are liable to a painful and often incurable disease of the jaw-bone. In the earlier periods of the manufacture of phosphorus matches there was considerable mortality from this cause, but it has been found that when close attention is paid to ventilation and cleanliness the danger is exceedingly slight.

The objections to the use of ordinary phosphorus can, however, be met in another way. Curiously enough, phosphorus is an element which exists in two forms. Just as an actor may represent two different characters in the same play, so phosphorus is sometimes a pale yellow,

waxy solid, very poisonous and very easily inflamed; at other times it is a red powder, not poisonous, and much less readily ignited. Regarded superficially, these two substances are absolutely different, but they are really the same element in different garb, and chemists have found a way of changing yellow phosphorus into red, or red into yellow. This matter has already been discussed at length in Chapter V.

Soon after red phosphorus was discovered, it was suggested that the disadvantages of using the ordinary yellow phosphorus in matches might be avoided by substituting the red form, on account of its being non-poisonous and less readily inflamed. Attempts were accordingly made to tip matches with mixtures containing red phosphorus, but these were not very successful. A certain Swede, however, ultimately proposed that, instead of putting the red phosphorus at the end of the match, it might be put on the surface on which the match was to be rubbed. This idea was worked out with complete success, and has led to what are now known as "safety matches." These matches will not ignite with ordinary friction on a rough surface; they will strike only on the prepared surface on the box, consisting very generally of red phosphorus, gum, and powdered glass. In order still further to diminish risk of fire, the stems of safety matches are frequently soaked in some chemical, such as alum or magnesium sulphate, so that when the burning match is blown out the wood immediately ceases to glow. A splint of ordinary dry wood, on the other hand, will continue to glow for a little after it has ceased to burn. This the reader can easily verify for himself.

The number of matches manufactured nowadays is enormous. It is estimated that in England alone, 300

millions are turned out daily, and that for each million of matches about one pound of phosphorus is required. The forty or fifty tons of phosphorus annually used in England for tipping matches are obtained from bones, which contain a large proportion of phosphate of lime. The high rate at which matches are turned out has become possible only by the introduction of ingenious labour-saving machinery, and no one who has not been through a match factory can realise how much is done in this direction.

Another curious device for the production of fire was brought out by Döbereiner in 1823. The lamp known by his name is no longer used, but it was based on a very interesting principle, and therefore deserves consideration.

We have seen that hydrogen is a combustible gas, and if we bring a light close to a nozzle from which hydrogen is escaping, it will take fire; that is, the hydrogen combines with the oxygen of the air at a high temperature, forming water vapour. At ordinary temperatures, on the other hand, hydrogen and oxygen are generally indifferent to each other. There is, however, one substance which is able to promote the union of hydrogen and oxygen, even under these conditions, namely spongy platinum—that is, platinum in a very finely-divided condition. Platinum is usually a compact white metal, heavier than gold, but by special chemical treatment it can be obtained as a dark, porous powder, and in this condition it is extremely active. If instead of bringing a flame to the nozzle from which hydrogen is issuing, we hold a little spongy platinum in the gas, the metal begins to glow and presently the hydrogen catches fire.

A very pretty instance this of what is known as "catalytic" action, a term denoting the curious effect which

some substances have in promoting a chemical action without themselves being altered thereby. The platinum, for instance, which induces the hydrogen and oxygen to combine so readily, is found to be unchanged at the end, and this is the case also in other processes where finely-divided platinum behaves as a catalytic agent. Its action has evidently something to do with the very large surface which is exposed by the porous, finely-divided metal, but opinions differ as to the correct explanation. Some think that the gases condense in the surface of the platinum, and are thus brought into closer contact—the platinum surface acting as a sort of birdlime for the flying molecules; others consider that the platinum first lays hold of the oxygen molecules to form a compound, and then meekly delivers them over to the hydrogen, with the net result that water is formed, and the platinum is left as it was at the beginning, with nothing to show for its labour.

Although Döbereiner's lamp has gone out in more senses than one, there are some modern devices based on the same principle. Many incandescent burners used to be provided with a little piece of platinum above the jet, so that when the gas was turned on, it would light without the help of a match. This arrangement has gone out of use now, largely because the platinum rapidly deteriorates in efficiency and finally loses its power of igniting the gas.

Another piece of apparatus, based on the same principle, is a cigar-lighter which is sold at the present time. This consists of a small metal vessel provided with a cap; the vessel holds some volatile spirit, and attached to the cap there is a piece of very fine platinum wire. When this is held in the vapour of the spirit,

while air has access to the vessel, the spirit combines with the oxygen under the influence of the platinum, heat is produced, the platinum glows, and finally the spirit bursts into flame.

Reference has just been made to the very high catalytic power of platinum when it is in a finely-divided condition. Generally speaking, it may be said that finely-divided matter behaves differently in many respects from compact matter of the same kind. It is, for example, a consequence of the law of gravitation that solid particles in the air soon fall to the ground, but if they are infinitesimally small they may travel quite a long distance without coming to earth. Thus the beautiful sunsets seen in England in 1883 were attributed to the presence of very fine dust in the atmosphere, carried all the way from a volcanic eruption on the other side of the globe.

In regard also to combustion finely-divided substances have somewhat peculiar manners. Everybody would regard iron and lead as elements of the most staid and sober temperament; and yet it is possible to obtain these metals in a state of such fine division, that when they are thrown out of any vessel into the air, they take fire of their own accord. The finely-divided substance has relatively a much greater surface than the compact substance, and the rate of rusting or oxidation is thereby so much increased that incandescence is observed; the process of combustion, which is slow under ordinary conditions, becomes very rapid. The phenomenon might be described as "spontaneous combustion," but the reader should clearly understand that the chemical change which takes place when finely divided iron or lead take fire in air is exactly the same as when

they rust; the only difference is that the latter change is spread over a much longer time.

There are other cases in which combustion appears to take place without any obvious cause, and to which the term "spontaneous" is applied. Stacks of hay occasionally take fire of their own accord, and heaps of cotton waste or rags impregnated with oil have been frequently found to exhibit a similar behaviour. But however "spontaneous" the occurrence may seem to be, there is in each case a sufficient reason for the combustion. In the first case the hay has been stacked while still moist, and in these circumstances fermentation sets in. Now fermentation is a chemical change of the constituents of the hay, promoted by the presence of minute organisms, and this change, like most chemical reactions, is accompanied by the evolution of heat. If the hay were lying out in the open, this heat would be dissipated at once, but in the inside of a stack it cannot escape so easily; it accumulates more and more as the fermentation process goes on and ultimately the temperature rises so high that the hay takes fire.

The explanation is different in the case of the oily rags or cotton waste. Many oils are readily oxidised by the oxygen of the air, and when such oils are spread over the extensive surface of rags or waste the oxidation takes place very rapidly. The rags and waste being bad conductors, the heat generated in the oxidation is rapidly accumulated, and finally leads to the so-called "spontaneous combustion."

In both these cases the chemical change involved is a slow combustion at the beginning, and becomes rapid at the end only because the heat generated in the process has been unable to escape. With rising tempera-

ture a chemical change invariably becomes quicker and quicker, hence as the heat accumulates in the hay or the cotton waste, the chemical forces become more and more impetuous and ultimately lead to a general conflagration. The affair, in fact, resembles the accumulation of money at compound interest.

Haystacks are not the sort of thing that the ordinary individual can experiment with, but there is one very simple example of the way in which the heat effect accompanying a slow combustion may be accumulated. If iron filings are mixed with sawdust and a little water is added, then after a few hours steam will be seen to come off from the mixture. Now the heat evolved during rusting cannot be detected in ordinary circumstances, but in this little experiment the non-conducting sawdust allows the heat to accumulate until it is obvious to the senses.

There was another kind of spontaneous combustion in which people believed at one time, namely, the spontaneous combustion of human beings. It was supposed that a living human body might be consumed by fire spontaneously generated in the internal organs. In the *Philosophical Transactions of the Royal Society* for 1744, for example, one finds a communication to the following effect:—"About seventeen years ago, three noblemen, whose names for decency's sake I will not publish, drank by emulation strong liquors, and two of them died, scorched and suffocated by a flame forcing itself from the stomach." So widespread was the belief in the possible spontaneous combustion of human beings that the great chemist Liebig thought it worth while to deal with the question and to record his view that "while a fat dead body charged with alcohol may perhaps burn, a living

body in which the blood is circulating cannot take fire spontaneously." The story of this curious belief shows how easy it is, firstly, to make wrong observations, and, secondly, even when the facts have been correctly ascertained, to rush at the first explanation which suggests itself.

CHAPTER XII

NATURE'S STORES OF FUEL

IT is all very well to be able to make fire, but our achievements in this direction would be of little use if Nature did not supply us liberally with combustible substances or fuels. So far as combination with oxygen and production of heat and light are concerned, a great many substances might be called fuels, but the name is generally restricted to those which contain the element carbon in some form, and which are obtained in large quantities on or under the surface of the earth. Some reference has already been made to these carbonaceous fuels, but much more remains to be said on this interesting topic. The process of combustion is perhaps the most fundamental chemical change with which we are acquainted, and to our modern world, with all its travel, industry, and social life, the production and maintenance of fire are almost as essential as air and water are to the human body.

In some cases the fuels supplied by Nature are available directly for man's use without any other than the simplest treatment. Wood and peat, for example, need only to be cut and dried before they are in condition for burning, while in the case of coal the only necessary preliminary is the cutting and raising to the surface.

These three fuels, wood, peat, and coal, represent three stages in the history of the vegetable world. Living

wood, apart from the large amount of water which it contains, consists chiefly of cellulose, a compound of the three elements, carbon, hydrogen, and oxygen. If the wood dies and is allowed to lie in the soil where it has grown, a remarkable series of chemical changes sets in. In many cases the fallen forests and jungles of the past have been submerged and then covered over with alluvial deposits of clay and sand, so that what was once a luxuriant vegetation on the surface is now buried many feet below.

Now when wood or any other vegetable matter containing cellulose is kept below water or in a moist soil, the relative proportions of the carbon, hydrogen, and oxygen which made up the cellulose begin to change. Decomposition and fermentation set in, the hydrogen is gradually eliminated in the form of marsh gas—a combustible compound of carbon and hydrogen—and the oxygen in the form of carbon dioxide. Any one who pokes a stick into a stagnant pool at the bottom of which vegetable matter is decomposing will observe bubbles of gas rising to the surface. These bubbles have been examined by chemists, and are found actually to contain carbon dioxide and marsh gas.

The result of these slow changes—extending over a long period—is that instead of cellulose there is left a carbonaceous mass containing a very much higher percentage of carbon than the original wood. If the decomposition has been going on for a very long time and at some depth below the surface, the product is a compact coal, containing relatively small quantities of hydrogen and oxygen. Vegetable matter of more recent date will not have been carbonised to the same extent, and will have reached the stage represented by brown coal or

lignite. Peat, again, is vegetable matter—chiefly moss—which has been undergoing decomposition and carbonisation for a very much shorter time, and which, being on the surface, has not been subjected to the same pressure as coal, and is therefore less compact.

A few figures will show how the amounts of hydrogen and oxygen diminish regularly as we pass from wood to a hard coal like anthracite. To make the figures comparable, the amount of carbon is put as equal to 100 in each case.

	Carbon.	Hydrogen.	Oxygen.
Wood	100	12	83
Peat	100	9	56
Lignite . . .	100	8	42
Bituminous coal . .	100	6	21
Anthracite . . .	100	3	2

Corresponding to the gradual alteration in composition, there is a change also in the way these fuels behave when they are burned. For a brightly blazing fire there is nothing like wood, the reason being that, when it is heated, quantities of inflammable gas are given off; hence wood catches fire much more easily than the other solid fuels, and when it has ignited it burns with a larger amount of flame, for flame is simply burning gas. The inflammable vapours given off from heated wood consist to a large extent of hydrocarbons—that is, compounds of carbon and hydrogen. Wood, therefore, which has undergone an age-long decay, and which has in the process lost the greater part of its hydrogen, will be able to yield little or no inflammable gas when heated. Take anthracite, for example—a species of coal which is largely mined in Wales; it contains a very high proportion of carbon, and

very little hydrogen and oxygen. When heated, it gives off practically no inflammable vapour, and this makes it very difficult to ignite; for the same reason, even when it has been successfully ignited, it burns with very little flame or smoke. These characteristics make anthracite unsuitable for domestic use; it can be kept burning only in a strong draught, and is accordingly chiefly employed in boiler furnaces.

The solid fuels which have been considered in the foregoing paragraphs are all directly supplied by Nature, and are to be had more or less for the gathering. In this little island we pick up over 200,000,000 tons of coal every year, and we may well ask how long this will continue to be possible. Shall we be able to draw upon Nature's stores for an indefinite period? Is it time to consider what we should do if the coal supply of the world ran out?

Before attempting to answer these questions, we must recall the fact that Nature supplies us also with liquid fuel, yielding it to us with a very slight expenditure of energy on our part. It has long been known that in certain countries there were indications of the presence of oil in the earth's crust, but it was only forty or fifty years ago that a systematic search was made. About that time a certain American engineer drove an iron pipe from the surface down through the rock, and was surprised to find that when the pipe had gone down about thirty-four feet, oil rose nearly to the top. He had in fact "struck oil." This discovery, of course, led to other attempts to tap the subterranean oil stores, with the result that to-day whole districts in the United States and Russia—the two countries which supply by far the greater part of the world's liquid fuel—are given over to "oil-bearing."

Sometimes the oil has to be pumped up like water from a well, but in other cases the oil in the internal reservoirs is under pressure, and so soon as an opening is provided it spouts out with great force.

It might be thought an easy matter to collect the oil which comes up these wells, but it is frequently very difficult, especially when the boring has just been made, and the oil is forced out under pressure. A certain well in Baku—the Russian oil-bearing district—tapped in 1886, began to spout with such vehemence that the whole surrounding country was deluged. For a time nothing could be done to stop the outflow, and many thousand tons of oil were lost. The great pressure which sometimes exists in the subterranean reservoirs was well shown by another fountain which burst out a few months later and rose to a height of 350 feet; the escape in this case was so great that it formed an extensive petroleum lake, and overflowed into the Caspian Sea.

The crude petroleum obtained from the American or Russian oil-wells must be subjected to chemical treatment before it is ready for the market. It is distilled, and the volatile portions of the oil are thus separated from the heavier portions. The reader would be quite surprised to find what a number of distinct products can thus be separated from natural petroleum by the simple process of distillation.

The most volatile portions of the petroleum yield naphtha and petrol, the latter substance now largely in demand in those days of motor cars. The petroleum which distils over at a somewhat higher temperature is used for illuminating purposes, and it is in this form of lamp oil that the bulk of the American petroleum ultimately comes into the market. After the petroleum

suitable for lighting has been distilled off, there is next obtained a heavy oily portion which may be used as a fuel or for lubricating purposes, while, last of all, there is a residue from which may be extracted such useful substances as vaseline and paraffin wax, the latter employed very largely in the manufacture of candles.

Closely allied to the petroleum of Pennsylvania or Baku is so-called "natural gas," which, in fact, frequently makes its appearance along with the petroleum. From the chemical point of view, it is extremely similar to petroleum, consisting largely of hydrocarbons; these, however, are still more volatile than the hydrocarbons present in petroleum, and are therefore not found in the liquid condition.

In the United States enormous quantities of natural gas are obtained, so much so that in many districts the manufacture of coal gas for lighting and heating purposes is quite superfluous. We do not, however, require to travel to the United States to find natural gas. There is actually a supply of it in England, although not on a large scale. It was discovered in 1893, as a bore-hole was being sunk at Heathfield, in Sussex, for the purpose of obtaining water. When the boring had reached a depth of over 200 feet, no water had been got, but an inflammable gas issued from the bore-hole. Some three years later another boring was made in the same neighbourhood, and at a depth of 312 feet gas was met with in considerable quantity. The supply was under great pressure, for when ignited it gave a flame 16 feet high. Obviously one of Nature's gasometers had been tapped, and since then this natural gas has been used regularly in the immediate neighbourhood for lighting and heating purposes to the extent of about 1000 cubic feet per day.

The gas consists almost exclusively of methane or marsh gas, the simplest compound of carbon and hydrogen.

The origin of solid fuel has already been discussed and is fairly evident, but it is much more difficult to specify the source of all the petroleum which has been obtained so abundantly during the last forty years. Some authorities assign to it an inorganic origin, and suppose that the hydrocarbons of which petroleum consists have been produced by the action of water on carbides. These substances are compounds of metals with carbon, and are decomposed by water in such a way that the carbon of the carbide forms a new compound—a hydrocarbon—with the hydrogen in the water. Many readers doubtless are familiar with one carbide which is in common use, namely, calcium carbide. This substance on contact with water generates acetylene, a hydrocarbon which has many advantages as an illuminating gas. Bicycle lamps, for example, are made in which acetylene is burned, the gas being prepared in the lamp by allowing water to drop on lumps of calcium carbide. So it may be supposed that water, penetrating through fissures in the crust of the earth, has acted on subterranean masses of carbides with the production of petroleum.

Another explanation, which on the whole has more support, regards petroleum as derived from an organic source, animal rather than vegetable. According to this view, the animal remains of past ages have undergone a change, whereby all nitrogenous and other matters, except the fats, were removed. Subsequently these fats, being subjected to distillation by the combined action of heat and pressure, or of pressure alone, yielded the petroleum which we get to-day.

In connection with all these fuel supplies — coal,

petroleum, and natural gas—a question of the utmost importance arises, to which reference has already been made. We are using up these fuels at an enormous rate, and there is no reason to suppose that the stores are being replenished at anything like the rate at which they are being consumed. In this respect we are, in fact, living on our capital, and, moreover, we do not know what is its amount. Estimates have indeed been made of the probable duration of our coal supplies, and Royal Commissions have dealt with the subject. The authorities are divided, but, on the whole, it seems we may reckon on our coal lasting for the matter of five hundred years or thereabouts, even when allowance is made for the probable increase in the consumption. It must be remembered also, for our comfort, that new coalfields are occasionally discovered, as was the case recently in the county of Kent. The Kentish collieries mean a substantial addition to our coal capital, and they may outlast the older ones in the north, so that some day it may be necessary to carry coals even to Newcastle.

Estimates like the foregoing are based on the actual inspection of the seams of coal which have been discovered, their thickness and extent, but who will be bold enough to say how long the subterranean reservoirs will keep us supplied with oil and gas? Human eyes have never seen, nor ever will see, what these hidden reservoirs contain. As a matter of fact, signs are not wanting that the stock of petroleum and natural gas is beginning to run short. The output of oil, it is true, is increasing, but this is due, not to any natural increase given by the existing wells, but to an increase in their number. The oil-yielding wells are very short-lived, and as new ones are continually being opened, the available oil-fields will soon be entirely covered.

We must not forget to include in our fuel capital the vast stock of timber on the surface of the globe, and the enormous quantities also of peat found in many countries. How far may we regard these as reliable sources of fuel? Wood, is, of course burned in many countries where there is a large extent of forest, but it would be absolute madness to use up all our timber in this way. It is the vegetation of the world which, as we shall see, is the necessary counterpart of animal life, and gradually to cut down all the forests on the face of the globe would be a suicidal policy. Besides, there is a large demand for timber for architectural and constructive purposes, and even as matters are at present, the forest-covered land of North America and Europe is being laid bare at a rapidly increasing rate. Trees do not grow in a hurry, and once the primeval forests are cut down, the keeping up of a supply of timber by planted trees is hardly feasible.

And what about peat? In Ireland alone there are over 1,000,000 acres of peat bogs, and it is estimated that an acre of a bog of an average depth of even 8 feet would yield about 1250 tons of dried peat. In Russia there are about 100,000,000 acres of bogs, so that altogether the fuel stored up in the form of peat must be very considerable. What militates against the use of peat as a fuel is the very large amount of moisture which it holds. When freshly dug it may contain as much as 80 to 90 per cent. of water, and the problem is how best to get rid of this and obtain the fibre of the peat in a condition fit for burning. The usual method of exposing the wet peat to air until it is dry requires much time and space. It is further a very bulky fuel, and, probably owing to these causes, the output of peat has never been much greater than sufficed for local de-

mands. In recent years, however, great advances have been made in the utilisation of peat. Methods have been devised of squeezing out the water by mechanical means, and compressing the combustible fibres into briquettes; these are not only more compact than the air-dried peat, but have also a higher heating power.

It is conceivable that in the distant future of the world's history there may come a time when, apart from timber, the natural stores of fuel—coal, peat, petroleum, and natural gas—are completely or almost exhausted. What then?

Necessity is the mother of invention, and we may be sure that before things shall have come to such a pass, the ingenuity of man will discover a way out of the difficulty. As a matter of fact, there are already indications that alcohol is to be the fuel of the future. In the form of methylated spirit it is used to a very small extent at the present day, but it looks as if it were to survive as a fuel when all others have gone. When every oil-well is dry, when a piece of coal can be seen only in a museum, and when the peat bogs are no more, then alcohol, if no better substance has been discovered in the meantime, will come to its own as a fuel.

"All very nice," the reader may say, "but how is the alcohol to be produced in the large quantities which will be necessary?" By the simple and time-honoured operations of growing potatoes, wheat, rice, beetroot, and similar substances. From these alcohol may be obtained by fermentation, as will be shown in a future chapter. To those who doubt whether alcohol could be used as fuel, say in driving an engine, the best reply is that the thing has been done. Experiments have shown that alcohol can be employed with satisfactory results in place

By permission of *Charles Dawson, Esq.*

Natural Gas in England

Some twelve years ago a supply of natural gas was accidentally discovered at Heathfield in Sussex, while a bore-hole for water was under construction. A strong smell of "gas" had been noticed round the hole, and on the application of a light a flame sprang up to the height of fifteen to sixteen feet. The supply of gas is not yet exhausted and has been used for several years in lighting Heathfield railway station.

of petrol, and it has certain advantages over the latter fuel, such as greater safety in handling. At present, while the natural fuel is so abundant, the price of alcohol will prohibit its general use as a fuel; but it is at least a comfort to know that we have something promising in reserve.

CHAPTER XIII

MORE ABOUT FUEL

IN the foregoing chapter we have discussed the various natural fuels which are available for use without any more than a slight preliminary treatment. There are, however, other substances commonly classed as fuels to which no reference has yet been made—for example, charcoal, coke, and coal gas. Although these substances are to be regarded as fuels, they do not belong to the same category as wood, peat, coal, or petroleum. Unlike the latter fuels, they are not obtained directly from Nature; they are produced secondarily from the natural fuels by special treatment.

Generally speaking, the secondary fuels, charcoal, coke, and coal gas, are obtained by the process of destructive distillation. This operation sounds rather alarming, but it is one which most boys have performed on a small scale, and the principle of it is comparatively simple. In ordinary distillation, where a liquid is converted into a vapour, and this vapour is condensed by passing through a cooled tube, any products obtained in the distillate were already present in the original liquid. The products, however, of a dry or destructive distillation are not present as such in the original substance; they are only produced by its chemical decomposition.

The little experiment in destructive distillation which many readers have probably made consists in filling the

bowl of a clay pipe with little bits of coal, blocking up the mouth of the bowl with clay, and then heating it in a fire. When this is done, a gas will be found issuing from the end of the pipe stem, which will burn with a luminous flame. This gas is essentially the same as coal gas, and the method by which it has been obtained is destructive distillation—the process by which also charcoal, coke, and coal gas are obtained from the natural fuels. It is, of course, necessary that the natural fuels which are undergoing destructive distillation should be excluded from contact with air during the process—otherwise combustion would take place. What occurs then is that the carbon compounds in the natural fuel are chemically decomposed by the action of heat; the atoms of carbon, hydrogen, and oxygen are re-arranged, and new products are formed which did not exist as such in the original fuel.

The chemical decomposition which takes place in the dry distillation of wood or coal is exceedingly complex, and the number of products that can ultimately be obtained is very large indeed. But although this is so, the first crude products are only four in number, namely, gas, watery liquid, tar, and residue, these differing in character according as wood or coal is being subjected to distillation.

In the case of wood the process is sometimes carried out by stacking the wood, burning part of it, and using the heat so obtained to decompose the rest. This is a wasteful method, so far as most of the products are concerned, for no provision is made to catch those which are volatile. The residue is known as wood charcoal, and consists very largely of carbon, with small quantities of hydrogen, oxygen, and nitrogen, and a little ash or

mineral matter. Such a primitive method of converting wood into charcoal is frequently replaced by a more scientific procedure, in which the wood is heated in closed vessels or retorts, and provision is made for collecting or condensing any volatile matter.

In considering the use of wood as a fuel, we have seen that its ready combustibility is due to its giving off inflammable vapour. It is therefore not surprising to find that when wood is heated out of contact with air a quantity of gas is obtained. The main constituents of this gas are carbon dioxide, carbon monoxide, and marsh gas; the two latter are combustible, and although the gas has not much illuminating value, it may be used to heat the retorts. This is a simple example of the way in which the by-products of a manufacturing operation may be utilised so as to diminish the cost of production.

The volatile matter obtained by subjecting wood to dry distillation not only yields a combustible gas, but condenses partly to a tar and partly to a watery liquid. The latter yields acetic acid—the acid of vinegar—and wood spirit; this consists largely of methyl alcohol, and is added to rectified spirits of wine in order to produce methylated spirit. The object of thus "denaturing" ordinary alcohol is to provide a spirit which may be employed for industrial purposes, and which, at the same time, is not drinkable. Whether the latter condition is fulfilled is doubtful, for it is said that such methylated spirit is consumed as a beverage, to the injury of the revenue. Accordingly, the bulk of methylated spirit now sold has a small admixture of mineral naphtha or light petroleum to render the taste more objectionable.

When coal is subjected to destructive distillation the effects are in general the same as those obtained with

wood, but the character of the products differs in some important particulars. The gas which is given off on heating coal is of much more use for illuminating purposes, and is, in fact, after purification, nothing else than the common coal gas used throughout our towns. This consists largely of hydrogen and marsh gas, together with some carbon monoxide and small quantities of heavy hydrocarbons which are responsible for the illuminating power.

In the crude gas which comes from the retorts there are several undesirable constituents which must be removed before the gas can be supplied to the public. In addition to carbon, hydrogen, and oxygen, coal contains small quantities of the elements nitrogen and sulphur, and these appear to some extent in the coal gas in the form of ammonia—a compound of nitrogen and hydrogen—and sulphuretted hydrogen—a compound of sulphur and hydrogen. The ammonia collects mostly in the watery liquid, which accordingly becomes *alkaline*, in contrast with the *acid* watery liquid obtained in the destructive distillation of wood. The last traces of ammonia are removed from coal gas by "scrubbers"—towers packed with coke or brushwood over which a constant stream of water is trickling. The current of gas goes in the opposite direction, and as ammonia is very soluble in water, it is all removed before the gas issues at the top.

The sulphuretted hydrogen resulting from the above process, if it were allowed to remain in the coal gas, would on burning produce sulphur dioxide, and this, in anything more than a small quantity, would be a very objectionable addition to the atmosphere. The gas is accordingly passed through a series of purifiers,

containing slaked lime and iron oxide. The reader is already familiar with the first of these as being an alkaline substance, in virtue of which it readily absorbs anything of an acid nature which passes through the purifiers. Now both carbon dioxide, a little of which is sure to be present in the gas, and sulphuretted hydrogen are substances of an acid nature, and one would therefore expect them to be fixed by the lime. Sulphuretted hydrogen, however, is not absorbed by lime when it is mixed with carbon dioxide, so in order to insure the complete removal of the former the coal gas must also be passed over iron oxide. This substance, generally in the form of Irish bog ore, is at first very active in holding back the sulphuretted hydrogen, but as it absorbs more and more it gets exhausted, being gradually converted into sulphide of iron. A course of fresh air, however, is found to have a beneficial effect on its activity, hence the exhausted or "spent" oxide of iron is taken out of the purifiers and spread on the ground for a time. During this "rest cure" the sulphide of iron enters into a chemical reaction with the oxygen of the air, with the result that the element sulphur is liberated and iron oxide is re-generated. The material is then again capable of actively absorbing sulphuretted hydrogen, and is therefore returned to the purifiers until exhausted a second time. This process of "revivifying" the iron oxide may be repeated a good many times until the material has picked up about half its own weight of sulphur. It will then have lost its effectiveness as a purifier of coal gas, and is accordingly sold to the sulphuric acid manufacturer. As the proportion of sulphur in the original coal is not more than one or two per cent., this is a very instructive instance of the

value of gathering up the fragments; even the very impurities in the coal gas are made to contribute to the cost of its production.

This remark covers also the ammonia which is found in crude coal gas. As has been stated already, the destructive distillation of coal converts some of the nitrogen which it contains into ammonia, and this has turned out to be a very valuable by-product of coal-gas manufacture. From the watery liquid, in which it mostly collects, the ammonia is driven out by a current of steam; it is then passed into sulphuric acid, forming sulphate of ammonia, and the crystals of this substance are fished out from time to time. On the average, a ton of coal yields 20 lbs. of ammonium sulphate; the latter substance fetches a good price as a manure—about £10 per ton—and it makes, therefore, a very substantial contribution to the expense of producing the coal gas.

Other by-products obtained in the manufacture of coal gas are tar and coke. From coal tar so many interesting and useful substances are prepared that a special chapter must be devoted to their consideration, where we shall see that even from this uninviting and unpromising material many beautiful products may be extracted.

Coke is the residue in the retorts after all gas, tar, and ammonia have been driven off. The mineral matter or ash in the original coal is not volatile, so that it remains in the coke, which contains about ninety per cent. of carbon and small quantities of hydrogen, oxygen, nitrogen, and sulphur. Gas coke is used as a fuel, although the reader will understand that since the volatile combustible gases have been removed, it is rather

difficult to burn. In domestic use it must be mixed with coal, but in furnaces where there is a powerful draught, it is very satisfactory by itself and gives off no smoke. Large quantities of gas coke are employed in lime and cement-burning.

Such are the chief products of the destructive distillation of coal in the manufacture of coal gas. As a fuel, coal gas, if not particularly cheap, is comparatively clean, and certainly very convenient. Hitherto it has been used principally for lighting purposes, and we can best appreciate its convenience in that respect from the standpoint of our great-great-grandfathers. What seemed to them the marvel about coal gas was that no wick was required as in the lamps and candles with which they were familiar. So marvellous did they find it, that it was regarded as rather uncanny, and the lighting of gas lamps was at first thought to be a perilous undertaking.

Nowadays, electricity is a competitor with gas as an illuminant, but the latter is being increasingly employed as a fuel, and may be said to hold its own. In England there is a decided preference for the old-fashioned, cheery open coal fire, with all its accompaniments of ash, soot, and smoke; there is little doubt, however, that the gas fire or stove is gradually coming into favour on account both of its cleanliness and its convenience. In estimating the chances that coal gas will hold its own with electricity as a lighting and heating agent, the very important part played by the by-products of the gasworks must not be forgotten. Here, as in so many cases, it is the by-products which settle the question whether a given manufacture will pay or not.

Coke, which has been referred to as a by-product in

the manufacture of coal gas, is prepared in large quantities for its own sake. It is extensively used in metallurgical operations, that is, in the production of metals from their ores. The coke required for this purpose must be specially dense, and as free as possible from sulphur and ash. Gas coke does not adequately fulfil these conditions, and in Great Britain as much as twelve million tons of coal are destructively distilled every year in special ovens in order to get coke suitable for metallurgical purposes. This is frequently described as oven coke.

The use of coke in metallurgical operations is readily understood. In iron-smelting, for instance, the ore consists mainly of iron oxide, and when this is heated in the blast furnace with coke, the oxygen prefers to be in partnership with the carbon rather than with the iron, so that the latter is liberated, and is obtained from the blast furnace as molten metal.

Coal is not the only naturally occurring substance that is subjected to destructive distillation. In Scotland there is a very considerable industry founded on the winning of fuel oil by the destructive distillation of shale. This is a carbonaceous substance which differs from coal in that it contains a very much larger proportion, sometimes as much as 70 per cent., of mineral matter or ash. By the destructive distillation of a ton of shale about thirty gallons of crude oil can be obtained, which by further treatment is made to yield paraffin oil, lubricating oil, and paraffin wax.

Attempts have been made also to subject peat to destructive distillation, but these have generally ended in failure. The difficulties, however, are now being overcome, and quite recently a promising development has

taken place in South Germany, where a plant has been put down beside an extensive peat bog, and is turning out tar, paraffin, ammonia, and coke. If this process should be found commercially sound, we may yet see the peat bogs of Ireland being converted into productive ground, while at the same time a new industry will be available for the people.

Leaving out of account for the moment the tar, ammonia, and sulphur obtained as by-products in the destructive distillation of coal, we may regard the net result of the operation as giving us for fuel coke coal gas instead of coal. Now whereas coal is an exceedingly dirty fuel, both coke and coal gas are clean fuels, burning without smoke. Bearing this in mind, we might ask the question whether it would not be possible to modify the destructive distillation of coal in such a way as to obtain a coke-like product, which would, however, still retain enough gas-producing material to make it readily inflammable, and which would at the same time be a smokeless fuel. Experiments made during the last four or five years have shown that this is possible when the temperature of the retorts, instead of being raised to 1600° or 1700° Fahrenheit, as is usual in gasworks, is kept about 800°. The quantity of gas given off during the heating is not so large, but the half-coked coal left in the retorts, containing as it does a certain proportion of volatile matter, is a smokeless, easily ignited fuel. This product is now on the market under the name of coalite.

The convenience of gaseous fuel for many purposes has stimulated efforts on the part of chemists to convert carbon entirely into combustible gaseous products. It was discovered long ago that when a current of steam is passed through red-hot carbon, an inflammable gas is pro-

duced. The chemical reaction involved is very simple; the water is decomposed by the red-hot carbon, and the latter appropriates the oxygen, forming carbon monoxide. The hydrogen of the water is left in the free state, and issues from the furnace along with the carbon monoxide. Since both these gases are combustible, the reader will perceive that the simple passage of steam over red-hot carbon means the conversion of a solid into a gaseous fuel. The product is called "water gas," a term which must be carefully distinguished from "water vapour"; the latter is of course not combustible.

Simple as the foregoing process may seem to be on paper, many difficulties were experienced in making it work on a large scale. The decomposition of steam by carbonaceous fuel requires a large amount of heat, and it was soon found impracticable to supply this by external heating of the retorts containing the coke or coal. The device was accordingly adopted of heating the fuel internally by its partial combustion. Air is blown into the retort containing the ignited fuel, which is raised to incandescence by the heat given out in its own combustion; then, as soon as this condition is attained, the air blast is shut off and steam is blown into the retort. The formation of water gas at once begins, and is continued until the temperature falls below a certain limit, when the steam blast is shut off and air is once again blown in. It must be understood that the two parts of this operation, the air blow and the steam blow, are complementary to each other, the heat evolved in the first stage supplying the energy required in the second stage.

Water gas, this mixture of hydrogen and carbon monoxide, burns with a non-luminous flame, and, if it is

to be used for illuminating purposes, must either be carburetted—that is, provided with hydro-carbons to render its flame luminous, or used with incandescent mantles. In America water gas is frequently used in place of coal gas; in this country it is never supplied alone for lighting purposes, but is often mixed with coal gas. One objection to its use is the excessively poisonous nature of carbon monoxide, referred to in a previous chapter. On this ground it is considered unsafe to distribute to the public coal gas which contains more than about 16 per cent. of carbon monoxide.

Has the reader ever realised what an enormous amount of energy is stored up in a pound of coal, or a cubic foot of coal gas? When the fuel is burned this latent energy becomes manifest in the form of heat, and it is actually found that the heat given out when one pound of coal is burned would be sufficient to raise the temperature of *seven tons* of water 1° Fahrenheit—say from 60° to 61°. Now heat is convertible into other forms of energy, and may, for example, be transformed into mechanical energy; thus it has been shown that the quantity of heat which would raise the temperature of one pound of water from 60° to 61° would, if converted into mechanical energy, be able to raise a weight of 772 pounds through 1 foot, or, what is the same thing, a weight of one pound through 772 feet. By means of this mechanical equivalent of heat, as it has been called, some one has calculated that if the energy latent in one pound of coal were converted without loss into mechanical energy, it would do as much as five or six horses working for an hour.

But one must admit that this is quite an ideal process. ven in the best engines we can employ to convert the ent energy of fuel into mechanical energy only a

portion of the heat reappears in the form of useful work. In this respect the internal combustion engine, such as is used on a motor car, is much superior to the steam engine, by which we convert only about 10 per cent. of the heat value of the coal into power.

The power of different fuels to give out heat when burned—the calorific power, as it is called—varies very considerably. The heat given out in the combustion of one pound of coal, for example, is nearly twice as great as that liberated when one pound of dried wood is burned. The calorific power of petroleum, on the other hand, is nearly 30 per cent. greater than that of coal. In selecting a fuel, however, many other factors have to be borne in mind besides the calorific power; the prudent engineer has to consider the bulk of the fuel, its cost, its handling, and the readiness with which it may be fed into the engine. It is the total effect of all these factors on the balance-sheet that is the important thing from the commercial point of view.

From what source has all the energy latent in naturally occurring fuels been derived? George Stephenson, when he was asked what drove his locomotive, replied that it was "bottled-up sunshine," and he was not far wrong. The reader will ask how the bottling process was carried out; but that is another story, which must be postponed to a later chapter.

CHAPTER XIV

FLAME: WHAT IS IT?

THE reader will by this time have become fairly familiar with the conception of combustion, and he may be under the impression that, knowing what combustion is, he has nothing more to learn about flame. This would be a somewhat rash conclusion, for, to begin with, the one thing does not always accompany the other; there are cases of undoubted combustion in which there is no real flame. A little piece of charcoal, for example, burning in air or oxygen gives out no flame; it only glows.

As a matter of fact, it is only when the burning substance is in the form of gas or vapour that we get flame produced. It is true that many liquid and solid substances give a flame when they burn, but the production of the flame is preceded by their conversion into vapour. By holding a match to the wick of a candle we first melt and then vapourise the wax which is in the wick; the vapour catches fire and the candle is lit. Once this has been done, the heat of the flame keeps the wax round the base of the wick melted, the melted wax is sucked up the wick by capillary action, and at the top it is vapourised and ignited.

Flame, then, is something different from combustion, and may be defined as gaseous matter which has been raised to such a high temperature that it is obvious to

the eye. Solids begin to emit light when they are heated to about 900° Fahrenheit, but vapours must be raised to a very much higher temperature before they become visible. When a combustible vapour reacts chemically with the oxygen in the air, which is the supporter of combustion, the heat produced is intense enough to raise the vapour to the point of incandescence—a flame is produced.

We have spoken here of a combustible substance and a supporter of combustion as being necessary for the production of flame, but it is well to remember that these terms are purely relative. If we could picture this world and its inhabitants as quite different from what they are, and could imagine that the atmosphere round the globe was one of hydrogen instead of air, then the gas companies would have to supply us with oxygen for lighting and heating purposes. In such a world oxygen would be regarded as the combustible substance, and hydrogen as the supporter of combustion.

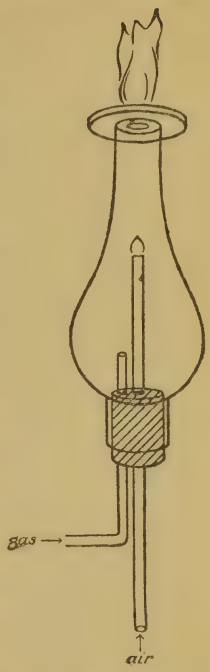


FIG. 4.—A sketch of an experiment showing that air can be burned in an atmosphere of coal gas.

It is, in fact, easy to show that air burns in coal gas quite as readily as coal gas burns in air. In the accompanying Fig. 4 the apparatus necessary for this experiment is shown. A lamp glass is fitted at the bottom with a cork, through which pass two tubes. The one which ends just above the cork is connected with the gas supply, the longer

one serves as an air passage. The top of the lamp glass is covered with an asbestos disc, in the middle of which there is a hole. When the gas is turned on, the air in the lamp glass is driven out, and the latter then contains an atmosphere of coal gas, the excess of which escapes through the disc at the top. This escaping gas may be lighted, and gives the ordinary flame of coal gas burning in air. If, now, the long tube which passes through the cork at the bottom is pushed up until it reaches the burning jet at the top, something at the end of this tube is seen to catch fire, and to remain alight, giving a visible flame even when the tube is drawn down again. The explanation of this interesting phenomenon is that air is being drawn up the long tube and is burning in the atmosphere of coal gas which surrounds the end of the tube. This apparatus, then, in which we can see both coal gas burning in air, and air burning in coal gas, shows that the terms "combustible," and "supporter of combustion" are interchangeable. There is no real distinction; the chemical process which goes on is the same in both the flames observed.

FIG. 5.—The flame of burning hydrogen.

When we come to look more closely at a flame we find that it has a structure. It may seem odd to speak of a mobile, elusive thing like a flame as having a structure, and certainly with a mixture such as coal gas being consumed at some ingenious modern burner, it is not easy to detect this structure. But if we take a simple gas such as hydrogen burning at the end of a plain round tube, we find the character of the flame to be exceedingly simple. The actual flame, as will be seen from the accompanying

sketch, is confined to a certain zone or sheath in which the combustion is going on, and this cone-like sheath is hollow.

That the cone of flame is hollow may be very easily and prettily shown by suspending the head of a match just above the end of the tube before lighting the gas. In spite of the burning gas the match in the inside remains unaffected (see Fig. 6, *a*). But we can go a step further and show that this hollow part of the flame contains unburnt gas by carefully putting one end of a narrow tube in the centre of the cone and applying a light to the other end some distance away. We get a flame there (see Fig. 6, *b*) simply because with the tube we have succeeded in leading off some of the unburnt gas from the centre of the cone.

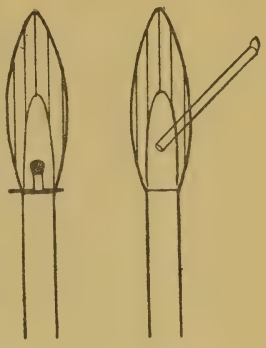


FIG. 6.—The hollow nature of a flame may be shown in various ways. A match-head suspended in the centre is not ignited by the flame, and with a piece of glass tube the unburnt gas from the centre of the flame can be led off and set alight at the end of the tube.

A candle flame and a coal-gas flame differ from a hydrogen flame only in that their structure is a little more complicated; their general characteristics are similar. In these two cases the dark hollow cone in which is the unburnt vapour is surrounded by a white, luminous zone, and this again by an outer envelope of flame which is non-luminous and very difficult to see. This outermost sheath is obviously the one for which there is an unlimited supply of oxygen, and anything which has escaped combustion in the luminous zone is there completely burned to carbon dioxide and water.

The luminosity of flame varies very remarkably with the nature of the combustible substance and with the conditions under which the combustion takes place. A hydrogen flame is quite non-luminous, carbon monoxide burns with a pale blue flame, while a candle or coal gas gives a bright white illumination. One cause of luminosity has been already referred to in a previous chapter, namely, the presence of solids which are made incandescent by the heat of the flame. A coal-gas flame contains in its luminous zone a host of unburnt carbon particles which are raised to a very high temperature and so give out a strong light. By mixing the gas with air before it comes to the nozzle of the burner these carbon particles are completely oxidised, and the flame becomes non-luminous. Such a non-luminous flame may, however, again be rendered useful for purposes of illumination by the artificial introduction of incombustible solids which are made incandescent by the heat of the flame. This is what is done in the ordinary incandescent gas burners and in the lime light.

There are other causes which determine the luminosity of a flame besides the presence of solid particles. There are some flames known which are characterised by very high illuminating power, and in which at the same time there cannot possibly be any solid particles present. For example, phosphorus burning in oxygen produces a dazzling light; but the oxide of phosphorus which results from the combustion is converted into a vapour at a red heat, and it is therefore impossible that it could exist in the solid state in the phosphorus flame, the temperature of which is far above the melting-point of platinum.

The well-known English chemist Frankland, who made many experiments on the nature of flame and the cause of

its luminosity, once took the trouble to carry candles up to the top of Mont Blanc, and was much struck by the comparatively small amount of light which they emitted when burning there. He traced this decrease of luminosity to the small atmospheric pressure prevailing at such a high level, and was able to show subsequently in his laboratory that the illuminating power of a candle is much reduced when it is burning in a partially exhausted vessel.

Since diminution of pressure reduces the luminosity of a flame, it might fairly be expected that increase of pressure would have the opposite effect; and so it turns out. A spirit-lamp, which, as the reader knows, gives practically no light when burning in air under ordinary conditions, gives a highly luminous flame when placed under a pressure of four atmospheres; and Frankland estimated that under a pressure of five or six atmospheres its luminosity would be equal to that of sperm oil burning under ordinary atmospheric pressure.

The influence of pressure on the luminosity of a flame is most strikingly illustrated by the effect of compression on burning hydrogen. This gas burns under ordinary conditions with a pale flame, absolutely useless for illuminating purposes, and it might be supposed that the want of luminosity is due to the absence of any solid product of combustion; water, the compound which results from the union of hydrogen and oxygen, is, of course, a vapour at the temperature of the flame. But if hydrogen is burned in oxygen at ten atmospheres pressure, the light emitted by the flame is sufficient to enable the observer to read a newspaper two feet away.

Plainly, therefore, the presence of solid particles is not the only thing on which the luminosity of flame

depends; the pressure under which the flame is burning has a decided influence.

We must recognise also another factor which has a bearing on the luminosity of a flame, and that is its temperature; the hotter a particular flame is, the higher is its luminosity as a general rule. One way of raising the temperature of a flame is to feed it with oxygen instead of air, and the result of doing this is sometimes surprising. The temperature, for instance, of a hydrogen flame in air is about 3600° Fahrenheit, while the same flame in an atmosphere of oxygen is some 1400° hotter. It is true that in the case of hydrogen no increase in luminosity results from this very remarkable rise of temperature, but the behaviour of hydrogen is exceptional. If a candle burning in air is transferred to a jar of oxygen, the flame shrinks in size but becomes distinctly more luminous, owing to the higher temperature.

We may get a hotter flame also by heating the air and the gas which are supplied to the burner, and such a rise in the temperature of the flame leads to increased luminosity. This was the principle applied in the so-called "regenerative" burners, in which the usual glass chimney was surrounded by a wider one closed at the bottom; the air, therefore, which fed the flame had to pass down between the chimneys, and was very considerably heated by contact with the inner one. Such devices, however, for securing increased luminosity have disappeared before the incandescent burner.

Not only may a flame be made hotter in various ways; it is possible also to lower its temperature. Admixture of an indifferent gas—that is, one which takes no part in the combustion—produces a marked cooling

effect, and a similar result is obtained by introducing into the flame some body which is a good conductor of heat. Indeed the temperature may be so much lowered by this latter device that the flame is extinguished. If, for example, a coil of copper wire is carefully placed over the wick of a burning taper, the flame goes out immediately.

In order to understand the possibility of this phenomenon, we must remember that every inflammable vapour has a certain ignition temperature. That is to say, for each vapour there is a point to which it must be heated in presence of air before it will catch fire and give a flame. Once it has been ignited, the heat given out by the flame as the result of the chemical action raises the incoming gas above the ignition temperature, and so the combustion continues.

Different substances have very different ignition temperatures. The vapour of carbon disulphide can be ignited by contact with a glass rod which has been heated only to 250° Fahrenheit, a little higher than the temperature of boiling water. A current of hydrogen issuing from a tube is ignited by sparks from a flint and steel, whereas marsh gas is quite indifferent to such treatment.

The possibility of cooling an inflamed vapour below its ignition temperature may be demonstrated in a very simple manner. If, as shown in Fig. 7, *a*, a piece of copper wire gauze is pressed down on a flame of burning coal gas (which, as we have already seen, contains a large proportion of marsh gas), no combustion takes place above the gauze, although it is easy to show that there is inflammable vapour there by bringing up a lighted match. Again, if we hold the gauze an inch

or two above a nozzle from which coal gas is issuing, we may light the gas above the gauze without the flame passing through to the lower side (see Fig. 7, *b*). The

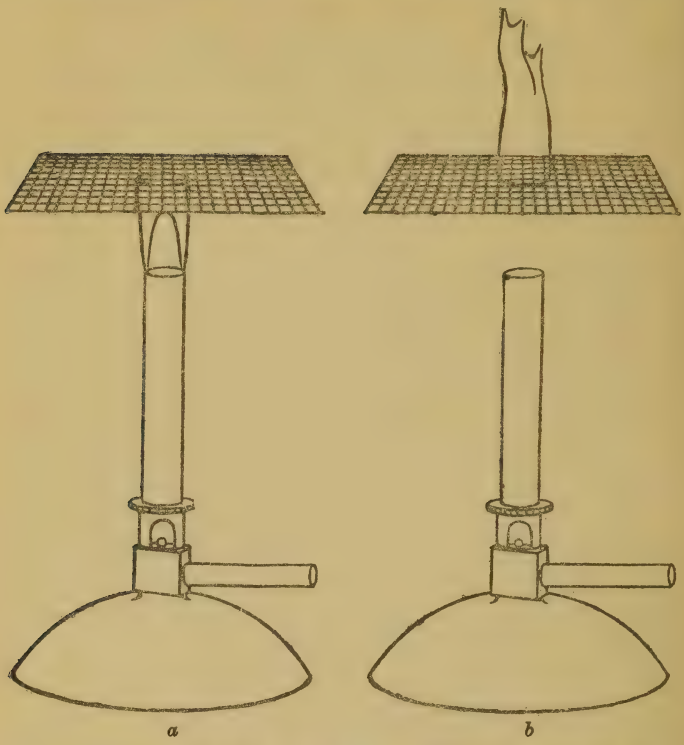


FIG. 7.—Showing the difficulty which a flame has in passing from one side to the other of a wire gauze.

reason of this curious result is that copper is an excellent conductor of heat, and the interposition of the gauze has such a cooling effect that the inflammable vapour on the other side from the flame is kept below its ignition temperature.

As already stated, the ignition temperature of hydrogen is lower than that of marsh gas, and if we attempted to obtain with hydrogen the results just described, we should not succeed. In all cases the hydrogen flame would strike through the gauze.

The remarkable power of metal gauze to limit the extension of a marsh gas flame was utilised long ago in the well-known miner's safety lamp devised by Sir Humphry Davy. Coal measures are frequently highly charged with marsh gas, and large quantities of this gas find their way into coal mines. Since this "fire-damp," as it is called, is inflammable, and forms a very explosive mixture with air, its presence in these mines is a source of great danger, and has repeatedly led to serious disasters.

The risk of using naked flames in such "gassy" mines had to be got over somehow, and Davy was able to show that if the oil flame in the miner's lamp was surrounded by wire gauze the danger of explosions was very much reduced. An explosive mixture of fire-damp and air will not as a rule be fired by such a lamp, but will indicate its presence by burning inside, and so warn the miner of danger. The action of the gauze in conducting away the heat prevents the explosive mixture outside reaching its ignition temperature.

The old form of Davy lamp has been found defective in some respects, and has been continuously improved; thus the wire gauze cut off a great deal of the light, so the lower part was replaced by a glass cylinder. Then it was found that a strong draught might blow the flame against and even through the gauze, with the result that an explosive mixture outside would be ignited. The newest form of the safety lamp

is therefore fitted, not only with a glass cylinder at the bottom to let the light out, but with an iron cylinder above to shield the lamp from draughts.

When the Davy lamp is brought into an atmosphere in which fire-damp is present, a so-called "cap" of pale blue flame is seen surmounting the ordinary luminous

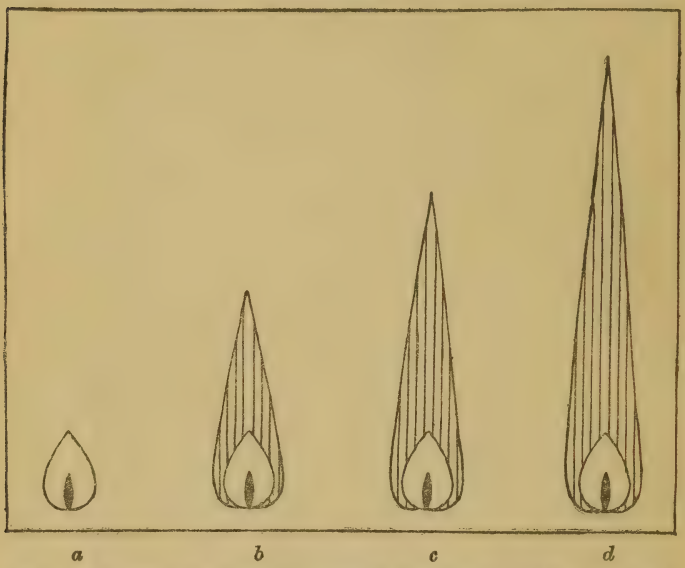


FIG. 8.—A flame of burning hydrogen is shown at (*a*). When this flame is brought into an atmosphere charged with fire-damp or marsh gas it is surmounted by a "cap," the length of which indicates the amount of dangerous vapour present. The caps shown at (*b*), (*c*), and (*d*) represent what is seen when the atmosphere surrounding the flame contains one-half, two, and three per cent. of marsh gas.

flame in the lamp. The length of this "cap" increases as the percentage of fire-damp in the surrounding atmosphere rises. Hence it will be seen that to the experienced eye the appearance of the Davy lamp flame serves as a

means of estimating the amount of fire-damp. It is only a rough estimate, however, which can be made in this way.

In recent years a much more accurate method of estimating the amount of fire-damp in mines or of petroleum in air has come into vogue. The apparatus used is really a safety lamp in which hydrogen is burned instead of oil. In an atmosphere containing fire-damp "caps" appear on the hydrogen flame just as in the ordinary safety lamp, but owing to the fact that the hydrogen flame is much less luminous than the oil flame, the "caps" are more easily seen and measured. The accompanying Fig. 8 shows the nature of these "flame caps," and the way in which their length varies with the amount of fire-damp in the atmosphere.

The gradual development of the Davy lamp is an interesting example of the way in which scientific work has been directed to the detection of danger and the preservation of life. It would indeed be difficult to estimate the saving of human lives which has resulted from Davy's discovery of the valuable properties of metal wire gauze in relation to a marsh gas flame.

Printed by BALLANTYNE, HANSON & Co.
Edinburgh & London

BRIGHAM YOUNG UNIVERSITY
3 1197 20982 1856